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PRINCIPAL CONTENTS IN THIS ISSUE:

	Page
A Note on the Absorption of Graphite in Hardening and Tempering Cast Iron. By Dr. J. E. Hurst .. .. *It is shown that cast iron can be hardened in which, prior to the hardening and tempering treatment, combined carbon is completely absent. Results of investigations are given.*	91–94
The Structural Changes in Copper Effected by Cold Rolling and Annealing	94
War-time Economics	95
Preliminary Researches on the Action of Water on Copper Pipes ..	96
Import Licensing of Aluminium ..	96
The Manufacture of Pig Iron in America. By William A. Haven *The primary object of the author is to describe the designs, equipment and practices which characterise practically all modern American blast furnaces.*	97–101
Hypersilid—A High-silicon Acid-resisting Alloy	102
Low Lead-Silver Alloys for Bearings	103–104
Practical Aspects of Working Aluminium and Its Alloys	105
The Production of Aluminium and Aluminium-Alloy Sheet. By William Ashcroft .. .. *The production and use of aluminium and aluminium sheet has made great progress in the last twenty years and in this article the author deals briefly with the main practical aspects of production.*	106–110
Working Aluminium-Alloy Tubes and Sections. By Norman L. Brown	110
The Production and Treatment of Aluminium-Alloy Castings. By a Special Contributor .. .. .. *The production of castings free from defects has been one of the most important problems of the industry, particularly those castings which are subsequently heat-treated and in this article the main factors involved in the production of aluminium-alloy castings are discussed.*	111–114
The Forging of Aluminium Alloys. By a Special Contributor .. .. *The fundamental procedure and principles of the forging of aluminium alloys are briefly outlined, and a comparison made with similar operations for steel.*	115–116
The Extrusion of Aluminium Alloys. By R. Worsdale .. .. *It is doubtful whether greater progress has been made in any other branch of the aluminium industry in recent years than that associated with the extrusion of the high-strength light alloys, and a brief outline of the technique employed in the process, given in this article, is both interesting and informative.*	117–120
Working Aluminium and Aluminium-Alloy Sheet. By a Special Contributor .. .. *The fabrication of aluminium and aluminium-alloy sheet involves such operations as bending, flanging, spinning, pressing and forming by means of a drop-hammer. The material is worked cold. Attention is directed to the working of the single heat-treated types of alloys.*	121–122
The Machining of Aluminium .. .. *Essential features in the machining of aluminium and its alloys are discussed.*	122
The Polishing, Plating and Anodising of the Aluminium Light Alloys. By E. E. Halls .. .. *The constantly growing field of technical applications of aluminium and its alloys has made it necessary to be able to vary the surface- Practical methods of surface treatment are discussed.*	123–126
Japanese Research on Aluminium Production	126
The Hot Galvanising of Wire. By a Special Contributor	127–128
Refractory Materials for Reverberatory Furnaces. By Alfred B. Searle .. *The seven essential parts of the reverberatory furnaces are discussed with respect to refractory materials.*	129–131
Temperature Control and Superheating for Cast Iron	132
Copper-Zirconium-Cadmium Bronze ..	133–134
The Structure and Mechanical Properties of Special Cast Irons	134
Metal Prices	136

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METALLURGIA

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FEBRUARY, 1940. VOL. XXI, No. 124.

A Note on the Absorption of Graphite in Hardening and Tempering Cast Iron

By Dr. J. E. Hurst

It is shown that cast iron can be hardened in which, prior to the hardening and tempering treatment, combined carbon is completely absent. Results of investigations are given which demonstrate the quench hardening effect in specimens of cast iron, in spite of the absence of combined carbon.

THE examination of quench-hardened specimens of cast iron under the microscope shows that, exactly as in the case of steels, the hardening effect is accompanied by the formation of the martensite constituent, and the effect of tempering is accompanied by the gradual breakdown of the martensitic structure. It is of some theoretical and general interest to note that the hardening effect can be obtained in specimens of cast iron, in which, prior to the hardening and tempering treatment, combined carbon is completely absent. The results of several investigations are available which demonstrate the quench-hardening effect in specimens of cast iron in which combined carbon was initially absent.

TABLE I.
CHEMICAL ANALYSES.

Condition.	Tot. C. %	Gr. C. %	C.C. %	Si. %	Mn. %	S. %	P. %	Ni. %	Cr. %
As Cast.....	3·15	2·68	0·47	2·62	1·16	0·07	0·61	0·49	0·34
Annealed.....	3·19	3·18	—	—	—	—	—	—	—

TABLE II.
MECHANICAL PROPERTIES.

Condition.	Modulus of Elasticity. Lb. per in.² × 10⁶.	Tensile Strength. Tons per in.²	Brinell Hardness. As Cast.	Brinell Hardness. O.H.	Brinell Hardness. O.H. & T.	Tempering Temperatures. °C.
As Cast ...	16·1	20·3	286	—	—	—
	15·4	20·5	269	—	—	—
As Cast ...	10·2	17·9	—	551	488	270
O.H. 875°C.	12·3	17·6	—	518	488	270
	12·8	20·0	—	488	435	350
	13·3	21·2	—	534	460	350
	14·8	22·2	—	488	390	400
	12·9	20·0	—	518	435	400
Annealed..	16·0	16·6	207	—	—	—
Annealed..	15·4	16·4	—	488	412	275
O.H. 875°C.	12·2	17·5	—	518	488	375

The example illustrated by the results in Table I is taken from a nickel-chromium alloy cast iron centrifugally cast. The chemical composition in the "as cast" condition, and the mechanical properties in this and the oil-hardened and tempered condition are given in Table II. The behaviour of this material on heat-treatment is in line with previous observations. Quenching is accompanied by an increase in hardness, and a decrease in tensile strength and modulus of elasticity. Subsequent tempering brings about a recovery in the strength and elastic properties, with a steady drop in hardness with increasing tempering temperature. A portion of this casting was submitted to annealing for a period of 24 hours at a temperature of 900° C. The effect of this, as disclosed by the chemical analysis, has been to decompose the combined carbon, and a trace only is recorded. The annealing treatment has brought about also a drop in the tensile strength and the hardness. Quenching and tempering this annealed material brings about a hardening effect approximately equal to that obtained with the material in the "as cast" condition, in spite of the absence of combined carbon.

A second example summarised in Table III and IV is of special interest in this connection. The two specimens were prepared in exactly the same manner by the centrifugal casting process, and differ only in phosphorus and combined carbon contents. The low phosphorous specimen had an almost complete ferrite-fine graphite structure, and the analysis shows combined carbon to be completely absent.

TABLE III.
CHEMICAL COMPOSITION.

Specimen No.	Tot. C. %.	Gr. %	C.C. %	Si. %	Mn. %	P. %
1	3·45	3·45	—	2·25	0·65	0·032
2	3·47	2·99	0·48	2·50	0·60	0·52

TABLE IV.
MECHANICAL PROPERTIES.

Specimen No.	Modulus of Rupture. Tons per in.² As Cast.	Modulus of Rupture. Tons per in.² O.H. & T. 275° C.	Modulus of Rupture. Tons per in.² O.H. & T. 450° C.	Brinell Hardness. 2 mm. 30 kg. As Cast.	Brinell Hardness. 2 mm. 30 kg. O.H. & T. 275° C.	Brinell Hardness. 2 mm. 30 kg. O.H. & T. 450° C.
1	20·7	49·1	45·2	168	475	412
2	29·1	41·0	42·3	210	410	380

TABLE V.

Specimen.	Tot. C.	Gr.	C.C.	Si.	Mn.	P.	Brinell Hardness. As Cast.	Brinell Hardness. O.H. & T. 275° C.	Brinell Hardness. O.H. & T. 450° C.
1	3·48	3·49	—	2·49	0·55	0·022	163	474	412
2	3·47	3·28	0·19	2·49	0·59	0·55	196	488	390
3	3·52	3·03	0·49	2·63	0·41	0·56	207	412	380
4	3·49	2·79	0·70	2·58	0·63	0·66	196	435	423

Comparing this specimen with that referred to in Table I, it will be appreciated that the combined carbon was absent in the "as cast" condition, and has not been removed by any subsequent annealing treatment. Specimen No. 2, with the higher phosphorus content, showed a normal graphite structure. In spite of the initial absence, of combined carbon in specimen No. 1, it will be seen that it hardens readily on quenching in oil from 875° C., and attains a higher hardness value than No. 2 in hardening and tempering. In the "as cast" condition the lower strength value characteristic of the ferrite-fine graphite structure is found in specimen No. 1, but, in spite of this, an increment of over 150% in strength is attained by

hardening and tempering, and the strength value is almost 25% higher than that obtained by the coarse graphite specimen.

An additional example is of interest. This is taken from the series of specimens whose chemical compositions are given in Table V. This, again, is a series of centrifugally-cast specimens of varying phosphorus contents, and again in the low phosphorus specimen No. 1 the chemical analysis shows the complete absence of combined carbon. The hardness results show clearly that this specimen has hardened to an even greater degree of hardness than the specimens containing an initially higher combined carbon content. As a matter of fact, in this specimen, although the chemical analysis showed combined carbon to be completely absent, the micro-structure showed the presence of very slight traces of pearlite. To make certain that hardening could take place in the complete absence of pearlite, specimens from the same castings were drastically annealed at 950° C. for a total period of 16 hours' heating and cooling, and even with the complete absence of initial pearlite the specimens were found to respond to the hardening and tempering treatment.

TABLE VI.
THE EFFECT OF WATER QUENCHING GREY CAST IRON FROM TEMPERATURES OF 900° C. to 950° C.

Specimen.	Duration of heating. Mins.	C.C. % by Colour.	Gr. %	Tot. C. % by Combustion.	Si. %	Mn. %	S. %	P. %
As Cast....	—	0·38	2·91	3·30	2·39	0·64	—	1·19
1	5	—	2·69	—	—	—	—	—
2	15	—	2·31	—	—	—	—	—
3	30	—	1·64	3·38	—	—	—	1·15
4	45	—	2·66	—	—	—	—	1·13

TABLE VII.

Specimen.	Tot. C. %	C.C. %	Gr. %	Si. %	Mn. %	S. %	P. %	Cr. %
1	3·44	0·79	2·65	2·43	0·91	0·074	0·63	0·27
2	3·58	0·83	2·73	2·41	1·43	0·063	0·62	0·26
3	3·48	0·72	2·76	2·09	2·00	0·036	0·63	0·20
4	3·37	0·86	2·51	2·34	3·10	0·034	0·64	0·21

It would appear from results of this nature that the hardening effect must in part be brought about by the solution of the graphite. It is known that on heating cast iron to temperatures of 900° to 950° C. some portion of the graphite can be dissolved and retained in the martensitic condition by quenching. This was shown by the author as far back as 1917[1], and it may be of some importance to repeat the main results obtained by him at that time. This is done in Table VI, and shows an increase in the combined carbon content due to quenching of from 0·38% to 1·74% equal to an absorption of graphite of 1·36% approximately. It is clear that this effect must be taken into consideration in the foundation of any conception of the mechanism of quench hardening. Some results of a preliminary study of the condition of the carbon in a series of cast irons in the quench-hardened and tempered condition are assembled in Tables VII and VIII. The chemical composition of the samples used are given in Table VIII and in Table IX the condition of the carbon for various oil-quenching and tempering treatments after annealing are given. For comparison, the carbon results are also given in the "as cast," and various oil-quenching and tempering treatments without annealing. These results are given in Table IX. The carbon determinations in all cases were carefully carried out. The samples were taken from the actual specimens used for the hardness determinations, and both the total carbon and the graphite contents determined by combustion. Duplicate determinations were made in each case, and in certain instances additional check determinations were made. In the oil-quenched condition there is clearly a diminution in the amount of graphite and an increase in the combined carbon content. In the tempered condition this diminution in the graphite and increase in the combined carbon content persists and even shows an apparent tendency to increase in magnitude up to tempering temperatures of 350° and 450° C., beyond which at the tempering temperature of 600° C. a tendency to revert more nearly to the original "as cast" condition is shown. In the specimens which had been annealed prior to subjection to the quench-hardening and tempering treatments the re-absorption of graphite and the apparent tendency of this to increase with increasing tempering temperatures up to 450° C. is clearly shown. Whether any special significance is to be attached to this apparent tendency for the graphite to diminish and the combined carbon content to increase due to tempering can be determined only by further experiment. The experimental procedure involving the treatment of separate specimens at each temperature introduces complications which may affect the magnitude of these changes in carbon contents. The significance of these results lies in the fact that they afford additional evidence over a range of chemical compositions of the re-solution of a portion of the graphite, with a consequent increase in the combined carbon contents due to the hardening and tempering, further that tempering at the higher temperatures is accompanied by the re-precipitation of some of this re-dissolved graphite. In addition, this re-absorption of the graphite occurs also in the material which has been hardened and tempered after having been subjected previously to an annealing treatment.

A further study of this subject has been made by Timmons, Crosby and Herzig[2]. In this study the effect of increasing the quenching temperature on the combined carbon content was determined on two cast irons commercially produced by a duplexing process. The chemical composition of the test-bars used is given in Table X.

TABLE VIII.
EFFECT OF ANNEALING, FOLLOWED BY OIL QUENCHING AND TEMPERING, ON THE CONDITION OF THE CARBON.

Condition.	No. 1. Mn. 0·91%			No. 2. Mn. 1·43%			No. 3. Mn. 2·0%			No. 4. Mn. 3·10%		
	C.C.	Gr.	Brinell.	C.C.	Gr.	Brinell.	C.C.	Gr.	Brinell.	C.C.	Gr.	Brinell.
Annealed 875° C. .. .. O.Q. 875° C.	0·98	2·28	416	0·99	2·56	441	1·24	2·24	551	1·19	2·20	489
Annealed 875° C. .. .. O.Q. 875° C. .. .. .. T. 300° C.	1·25	2·18	353	1·37	2·18	390	1·16	2·35	396	1·05	2·32	376
Annealed 875° C. .. .. O.Q. 875° C. .. .. .. T. 350° C.	1·08	2·35	327	1·48	2·07	320	1·19	2·29	310	1·08	2·38	346
Annealed 875° C. .. .. O.Q. 875° C. .. .. .. T. 400° C.	1·03	2·42	309	1·26	2·29	276	1·24	2·40	330	1·10	2·22	325
Annealed 875° C. .. .. O.Q. 875° C. .. .. .. T. 600° C.	1·00	2·50	255	1·26	2·29	231	1·13	2·35	245	1·25	2·14	285

Test-bars 1·2 in. dia. by 2 in. long were cut from standard test-bars and placed in a furnace standing at the desired quenching temperature. The samples were held in the furnace for a period of one hour and then immediately quenched in oil. The results of the hardness tests and the determinations of the combined carbon contents are assembled in Table XI.

These results together with an examination of the micro-structure show that at temperatures in the neighbourhood of 675° C. graphitisation begins and proceeds to completion if sufficient time is allowed, and at a rate dependent upon the chemical composition. In the case of the Cr-Ni-Mo alloy cast iron the presence of these alloys is to be regarded as preventing this graphitization proceeding to completion, although it is evident that partial graphitisation has occurred. The rate of graphitisation in an alloy iron of this type is so low that in the period of one hour the combined carbon content is reduced only to 0·45% from 0·70%. In both

1 Hurst, J. E. *J. Iron and Steel Inst.* Vol. II, page 125. 1917.

2 Timmons Crosbyand Herzig. A.F.A. Conference, May, 1939.

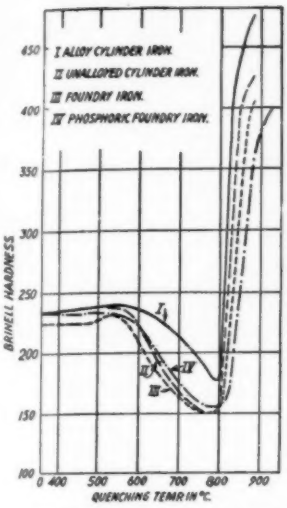
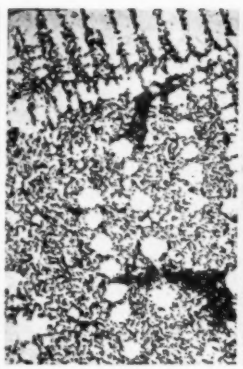


Fig. 1.—Schwartz and Vath experiments.



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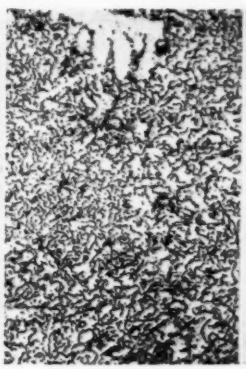

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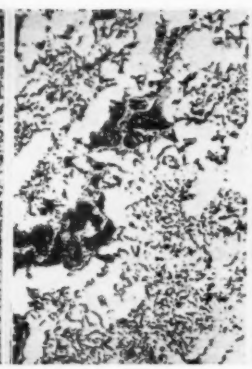

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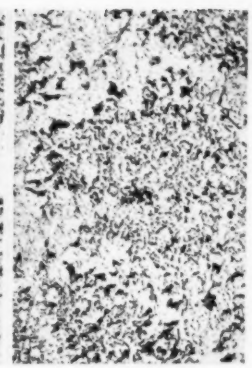


Fig. 5.

Hardened and tempered specimens possessing structure of ferrite-free graphite types.

cases when the irons were heated to higher temperatures re-absorption of the carbon occurred, and the structure of the iron became fully martensitic upon quenching. The Brinell hardness determinations also confirm the changes in carbon content, and it will be observed that quenching from a temperature of 760° C. is accompanied by a marked lowering of the hardness value and softening of the iron. These results confirm the observation that the hardening of cast iron by quenching is dependent to an important degree upon the amount of carbon which has been re-dissolved prior to the instant of quenching. They also confirm the experiments of Schwartz and Vath[3], who investigated the effect of quenching from different temperatures on four cast irons whose compositions are recorded in Table XII.

The hardness results obtained on quenching these irons from different temperatures are illustrated in Fig. 1.

TABLE X.

CHEMICAL COMPOSITION OF TEST-BARS (TIMMONS CROSBY AND HERZIG).

Description.	Tot.C.	C.C.%	Gr. %	Si. %	Mn. %	Mo. %	Cr. %	Ni. %
Plain Cast Iron "As Cast"	3·19	0·69	2·50	1·70	0·76	0·013	0·03	—
Cr-Ni-Mo Alloy Cast Iron "As Cast"	3·10	0·70	2·40	2·05	0·80	0·45	0·27	0·37

TABLE XI.

RESULTS OF TESTS ON QUENCHED SAMPLES OF CAST IRON (TIMMONS CROSBY AND HERZIG).

Condition.	Plain Cast Iron.		Cr-Ni-Mo Alloy Cast Iron.	
	C.C. %	Brinell Hardness.	C.C. %	Brinell Hardness.
As Cast	0·69	217	0·70	255
Quenched from 650° C. 1,200° F.	0·54	207	0·65	250
" " 675° C. 1,250° F	0·38	187	0·63	241
" " 700° C. 1,300° F.	0·09	170	0·59	229
" " 730° C. 1,350° F.	0·09	143	0·47	217
" " 760° C. 1,400° F.	—	137	0·45	197
" " 785° C. 1,450° F.	0·05	143	0·42	207
" " 815° C. 1,510° F.	0·47	269	0·60	444
" " 840° C. 1,550° F.	0·59	444	0·69	514
" " 875° C. 1,600° F.	0·67	477	0·76	607

TABLE IX.

Condition.	No. 1. Mn. 0·91%			No. 2. Mn. 1·43%			No. 3. Mn. 2·00%			No. 4. Mn. 3·10%		
	C.C	Gr.	Brinell.	C.C.	Gr.	Brinell.	C.C.	Gr.	Brinell.	C.C.	C.C.	Brinell.
As Cast	0·79	2·65	234	0·83	2·73	255	0·72	2·76	305	0·86	2·57	305
" " O.Q. 875° C	0·93	2·50	565	0·99	2·58	568	0·98	2·50	518	0·87	2·50	460
" " O.Q. 875° C. / " " T. 300° C.	0·98	2·49	534	1·15	2·40	534	1·13	2·35	460	0·88	2·51	423
" " O.Q. 875° C. / " " T. 350° C.	1·03	2·40	448	1·26	2·20	460	1·19	2·29	412	0·92	2·45	401
" " O.Q. 875° C. / T. 450° C.	1·08	2·35	371	1·15	2·46	380	1·19	2·29	352	1·07	2·30	371
" " O.Q. 875° C. / T. 600° C.	0·87	2·56	305	1·05	2·56	305	1·15	2·35	278	1·02	2·35	298

Quenching from temperatures in the range of 550° to 790° C. in each case is accompanied by a drop in hardness from the original "as cast" condition. From temperatures in excess of 775° to 790° C. quenching is accompanied by hardening, the maximum hardening effect being obtained with quenching temperatures in the neighbourhood of 900° C. These further results appear to confirm the view that the decomposition of the combined carbon initially present in the cast iron may be a preliminary to hardening by quenching from temperatures high enough to secure the solution of the graphite thus formed. Crosby and his collaborators showed that the decomposition of the combined carbon in plain unalloyed grey cast iron is exceedingly rapid and that relatively small additions of alloys have a marked effect in reducing the graphitization rate. This emphasises the importance of obtaining uniform temperatures high enough above the critical point to ensure the re-absorption of the graphite in hardening and tempering operations on plain grey cast iron. It will be apparent that the considerations governing the most effective quench hardening temperature in the case of cast irons are somewhat different from those of steels, and the importance of the re-absorption of the graphite cannot be overlooked.

In this connection it will be appreciated that the condition of the graphite also becomes of importance. There is reason to believe that the facility and rapidity with which graphite can be re-dissolved in cast irons heated to temperatures above the critical range is influenced by the size, character and method of distribution of this constituent. An indirect indication of the importance of this is to be had from a consideration of the mechanical strength properties and the micro-structure of the specimens referred to already in Table V. The mechanical test results obtained on these specimens after heat-treatment are given in Table XIII.

TABLE XII.

COMPOSITION OF CAST IRONS (SCHWARTZ AND VATH EXPERIMENTS).

Type of Cast Iron.	Tot. C.	Si. %	Mn.%	S. %	P. %	Ni. %	Cr. %
Alloyed Cylinder Iron	3·15	1·90	0·62	0·018	0·46	1·04	0·35
Non-alloy Cylinder Iron	3·02	2·03	0·62	0·032	0·55	—	—
Foundry Iron	2·99	1·92	0·62	0·030	0·73	—	—
Phosphoric Foundry Iron	3·20	2·45	0·70	0·105	1·37	—	—

The photo-micrographs of specimens No. 1 and 4 in the "as cast" and hardened and tempered 275° C. condition are given in Figs. 2, 3, 4, and 5. These specimens, as will be seen from the illustrations, possess structures of ferrite-free graphite type; well developed in the low phosphorus specimen Fig. 2, and diminishing in form and magnitude with increasing phosphorus content to a coarser

3 Schwartz and Vath. *Die Giesserei*. Vol. 21, page 345. 1934.

TABLE XIII.

Specimen.	Tensile Strength.			Permanent Set.		
	As Cast.	O.H. & T. 275°.	O.H. & T. 450°.	As Cast.	O.H. & T. 275°.	O.H. & T. 450°
1	22·8	48·2	44·5	9·95	3·56	5·0
2	27·2	42·5	43·5	21·7	7·70	5·0
3	28·0	41·25	43·3	15·1	6·25	5·35
4	23·2	37·30	36·2	22·2	5·85	4·7

graphite structure in Fig. 4, the high phosphorus specimen. The marked improvement in mechanical strength properties due to hardening and tempering, amounting to an increase of well over 100% in tensile strength in the low phosphorus specimens is also shown. The extent of this improvement is lowered in the higher phosphorus specimens, and it is impossible to resist the conclusion that these exceptional improvements in strength properties are associated with this structural condition of the graphite.

The Structural Changes in Copper Effected by Cold-Rolling and Annealing

THIS paper, by Dr. Maurice Cook and Dr. T. Ll. Richards,* is concerned with experiments which have been carried out on the deformation by cold-rolling of pure copper, and the subsequent recrystallisation on annealing, with a view to studying the mechanism of deformation and crystallisation. The material used was a commercial copper of H.C. quality, with a copper content of 99·95%, and in addition it contained oxygen, 0·03%; silver, 0·003%; iron, 0·005%; and lead, less than 0·001%.

To study the effect of varying amounts of cold-rolling on the structure of the metal, samples were prepared from one ingot of the above composition. It was hot-rolled from its original thickness of 4 in. to $1\frac{3}{4}$ in. From this stage onwards all the reductions were effected by cold-rolling, and six samples were prepared, all of which had a final thickness of 0·025 in., with final cold-rolling reductions of 10, 25, 50, 75, 85 and 97%. The scheme of rolling and annealing operations adopted in the production of these samples is given in Table I, from which it will be seen that all intermediate rolling reductions were of the order of 50%, the intermediate annealing operations being carried out at a temperature of 550° C.

TABLE I.

TREATMENT OF SAMPLES.

Ingot hot rolled to 1·75 in., annealed at 550° C., and cold rolled to 0·83 in. Subsequent reductions in the thicknesses are indicated below and all intermediate anneals were carried out at 550° C.

Final Rolling Reduction.					
10%	25%	50%	75%	85%	97%
0·83 in. anneal 0·40 in. anneal 0·20 in. anneal 0·10 in. anneal 0·055 in. anneal 0·028 in. anneal 0·025 in.	0·83 in. anneal 0·40 in. anneal 0·20 in. anneal 0·10 in. anneal 0·067 in. anneal 0·033 in. anneal 0·025 in.	0·83 in. anneal 0·40 in. anneal 0·20 in. anneal 0·10 in anneal 0·050 in. anneal 0·025 in.	0·83 in. anneal 0·40 in. anneal 0·20 in. anneal 0·10 in. anneal 0·025 in.	0·83 in. anneal 0·352 in. anneal 0·167 in. anneal 0·025 in.	0·83 in. anneal 0·025 in.

After the annealing operation carried out prior to the final cold-rolling reduction, all six samples had an average grain-size of 0·03—0·04 mm., and transmission photographs showed a random distribution of spots, indicating that the crystals in the metal at this stage had a random orientation.

In order to obtain specimens suitable for transmission photographs, pieces of the rolled metal were treated with a solution of 50% nitric acid to reduce the thickness to the order of 0·004 in., so that, in effect, it was the central plane of the strip that was examined. In one or two cases the surface layers were also examined, but the results were not found to show any sensible differences. For the glancing photographs, about 0·005 in. of metal was dissolved off each side to remove the surface layers, and photographs were taken with the X-ray beam perpendicular to the direction of rolling, and also with the beam almost parallel to the direction of rolling. Throughout all the work a molybdenum target was employed.

The study was made by both X-ray and microscopic methods. It is shown that in cold-rolling copper, deformation takes place in two stages: first, by a slip mechanism, which produces a measure of preferred orientation of the crystals—this preferred orientation, which is such that a $\{\bar{1}10\}$ plane is parallel to the surface of the strip and a <112> axis is in the rolling direction, restricts further deformation by slip; the second mechanism then becomes operative, namely, a breakdown of the crystals into minute blocks which glide over flow layers. This deformation leads to the development of a fibre texture which is, in reality, a double texture bearing a twinned relationship.

In strip cold-rolled with reductions in thickness of less than about 50%, no preferred orientation is present after annealing. With reductions in excess of about 50%, the presence of the fibre textures in the cold-rolled strip influences the mode of recrystallisation of the metal on annealing and two types of recrystallisation occur:

(1) After heavy reductions of the order of 97%, the two textures are so closely interdependent that they coalesce to form a single texture, the crystals having a preferred orientation such that a $\{100\}$ plane is parallel to the strip surface and a <100> axis is in the rolling direction. The degree of closeness of the textures necessary for complete recrystallisation of this type is of the order of 10^{-4} cm. The existence of the single texture is demonstrated also by the growth of large crystals in the annealed material after a further critical reduction and subsequent anneal.

(2) After a reduction of about 85%, a reduction which is insufficient to produce complete recrystallisation of the first type, a second type of recrystallisation is also present, in which the twin-fibre textures of the cold-worked strip recrystallise independently into two sets of crystals, each set having a preferred orientation corresponding to that of one or other of the twin-fibre textures. With reductions of less than 85%, but greater than 50%, it is probable that the recrystallisation, although somewhat indefinite, is of the second type only. By suitably adjusting the penultimate rolling and annealing conditions, complete recrystallisation of the second type can be obtained.

* *J. Inst. Metals*, **66**, 1940 (Advance copy).

Obituary

WE regret to record the death, on February 2, of Mr. Gordon D. Hardie, who for 17 years had acted as grinding wheel representative of the Carborundum Co., Ltd., for the Glasgow area.

METALLURGIA
THE BRITISH JOURNAL OF METALS.
INCORPORATING "THE METALLURGICAL ENGINEER"

War-Time Economics

THE primary object of the British Empire is to win this war and thus check wanton aggression. There can be no doubt that the British people are convinced that no immediate peace is possible, and they are prepared to carry the war through to a successful conclusion. But fighting alone does not win wars ; it was this we had in mind when, in our last issue, we exhorted the Government to keep the trade channels open. Apparently, from information since given in the House of Commons, this aspect of the war effort was recognised and the Government now contemplate a great drive for export trade.

The early months of the war has seen the establishment of controls which enabled the Government to buy vast quantities of essential commodities before the war had any appreciable effect on prices. These early manœuvres, which secured many advantages, seriously affected trade, and it is in this direction that adjustments can be made with a view to helping overseas trade. Whether a new Minister of War Economy is necessary to the success of such a drive is doubtful, since the work concerned is primarily the concern of the Board of Trade, but it is apparent that the tasks contemplated are to be carried out on such a great scale that more Government intervention will be exercised in the future than in the past. The importance with which the Government view this aspect of the war effort is seen in the Export Council, which the President of the Board of Trade, Sir Andrew Duncan, has set up. Composed of leading industrialists and trade unionists, and including representatives from the Treasury, the Ministry of Supply, and the Foreign Office, such a Council should be capable of co-ordinating and promoting immense trade drives, since although at first it was intended that the Council would function in an advisory capacity, it has been decided go give it executive powers.

The need has become apparent to concentrate on two main objects—war and exports. The latter has become increasingly vital, because of its bearing on questions of foreign exchange. The position is very different from that experienced in the war of 1914-18, when world trade operated on a credit basis ; although this system still operates, the extent is much more limited by the inroads of the barter system, which involves selling in order to buy. There are, of course, three main sources of revenue to meet the essential imports demanded by the war—they can be paid for from our foreign investments, from our gold reserve, or from our exports. The two former are limited, and can be regarded as the nation's capital reserve, which obviously must be maintained as high as possible. Exports, on the other hand, provide a source of income, fluctuating with the value of the exports, but the higher this income the less is the need for calling upon reserves of capital.

At the outbreak of war the nation was advised to spend ; this was probably due to certain panic measures adopted by sections of the community. Now that a more normal outlook is restored the need to save is becoming of paramount importance, which, in its broadest sense, involves the restriction of non-essential goods. Saving should have for its object the limitation of consumption, and if the goods are imported the reduced consumption facilitates the diversion of goods to war needs ; if, on the other hand, the goods are manufactured in this country, a great proportion will become available for export. Apart from this, however, reduced consumption of goods tends to prevent the rise of prices and wages and places the exporter in a reasonable position to compete in overseas markets.

It is encouraging to note that, following a temporary setback to British export trade, experienced as a result of the initial dislocation brought about by war, a good measure of recovery has been attained. As pointed out by the Hon. Rupert E. Becket, chairman of Westminster Bank, Ltd., Germany has been ruled out as a trader from the greater part of the Western world. This means the removal of a formidable competitor, especially as the exports of Britain and Germany, both highly industrialised countries, are similar in character. But this is not all. Other European countries also find their exports jeopardised by Germany's methods on the high seas, and some curtailment has naturally followed. Countries contiguous to Germany, and large customers of hers for that reason, find German pressure to trade with her often against their own national interests and political inclinations, and trade conducted in sterling has advantages over barter transactions.

Many countries, formerly large customers of Germany, now find that market for both imports and exports closed to them, and must look elsewhere for trade development; their sympathies frequently incline them to turn to Britain to fill the gap. These factors combine to open up favourable avenues for trade which in normal circumstances would never have presented themselves on so great a scale. It will be recognised, however, that neutral countries, which are not preoccupied with provision for actual warfare, are also well aware of these opportunities, and have more time to devote attention to their exploitation.

Unfortunately the difficulties experienced by manufacturers are much greater than in peace time. In many cases they are fully employed in war work for the use and equipment of the armed forces. In others there has been difficulty in getting the necessary raw materials and the hampering effect of the permits which have to be granted by the various controls. It is by no means an easy problem, but the appointment of the Exports Council augurs well for a concerted effort in smoothing out difficulties, in order to facilitate the manufacture of commodities for export, and also to organise and develop external markets and to arrange for necessary transport facilities. It should not be expected that early spectacular progress in increasing the export trade will result from this effort, the war at sea and the system of controls of both inward and outward cargoes are two of the many factors which mitigate against this, but there is evidence that the great work of the Allied Navies and Air Forces is achieving success.

It will be appreciated that the first few months of the war constitute a period of readjustment of the whole of the nation's economy. That this process is being accomplished with a minimum of serious dislocation reflects great credit on those who many months ago were obliged to formulate plans which could not be tried out in practice before a state of emergency arose. Mistakes have been made, and it is well that criticism has assisted to remedy them. Now that the economic aspects of the war are receiving wider attention, the concentration of our energies and powers, and the co-ordination of our resources on the job of winning the war will be more appreciated.

Preliminary Researches on the Action of Water on Copper Pipes

ALTHOUGH iron and steel mains are normally employed for the distribution of drinking water, lead or copper, being more corrosion-resistant, is usually preferred for the smaller-sized pipes used in domestic service, in order to avoid stoppage caused by the accumulation of corrosion products. A drawback to the use of lead pipes, however, is the risk of lead poisoning, which may occur with certain soft acid waters. Copper, on the other hand, is less poisonous than lead, amounts as great as 2 mg./litre being stated to be non-toxic. For these and other reasons copper has found extended application in domestic service systems in recent years.

Nevertheless, the amount of copper picked up by the water is important, since, in the first place, water containing copper is liable to cause localised corrosion of iron pipes and aluminium utensils; secondly, copper acts as an oxidation catalyst in accelerating the destruction by detergents of the peroxide type of textile fibres, such as cotton and artificial silk; and thirdly, copper results in the destruction of vitamin C during cooking.

A number of investigations on the action of drinking water on copper pipes have been carried out in the past, but systematic investigations of the relationship between the action of drinking water on copper pipes and the carbon dioxide and oxygen contents of water do not appear to have been carried out. Some preliminary laboratory researches have therefore been conducted at the Nooges Tekniske Høiskole, Trondheim, with copper pipes and drinking water containing various additions, under stagnant conditions. The main objects of these investigations, which are reported in a paper by Professor Dr. L. Tronstac and R. Veimo,* were to study the reactions governing the dissolution of copper and also to gain information concerning possible precautionary measures against attack of copper pipes by drinking water under active service.

Corrosion experiments were carried out with closed copper tubes and stagnant tap-water containing various additions. In agreement with the result of experiments on the solubility of copper compounds, and with theoretical considerations, it has been shown that copper compounds show an increase in solubility with increase in aggressive carbon dioxide content of the water, which may be explained by the formation of complexions. Cuprous compounds are less soluble than cupric compounds. Oxygen is essential for the corrosion of metallic copper in water and determines the total attack; it also influences the copper content of the water in contact with the metal. At the same time, corrosion and dissolution of copper are greatly affected by the presence of aggressive carbon dioxide (and, to a less extent, by combined carbon dioxide), especially at higher concentrations.

By additions of lime to *p*H 8·5, the content of copper in a tap-water, after standing for 24 hours at 18° C. in copper pipes, is appreciably reduced, but thereafter it increases with rising *p*H, as a result of cuprite formation. The copper content of stagnant water in a closed copper-pipe system reaches a maximum after a definite time of contact, depending on the carbon dioxide and oxygen contents of the water; but owing to the precipitation of surface films, it subsequently decreases to a limiting value corresponding to the equilibrium between cuprous and cupric ions and to the solubility of the corresponding corrosion products. In a closed copper-pipe system the oxygen in the water is chiefly consumed in the formation of superficial films. The dissolution of copper is accelerated by increasing temperature, but the final copper content of the water is little affected.

Addition of lime to the water to increase the *p*H to 8·5 is tentatively suggested as a remedial measure against attack of copper service-pipes by water.

* *J. Inst. Metals*, **66**, 1940 (Advance copy).

Import Licensing of Aluminium

AT the request of the Ministry of Supply the Board of Trade has issued an Order, the Import of Goods (Prohibition) (No. 3) Order, 1940, prohibiting, except under licence, the importation of aluminium and aluminium alloys containing more than 50% by weight of aluminium, other than machinery parts, in the form of ingots, notch-bars, lumps, cakes, sticks, billets, slabs, wire-bars, plates, sheet, strip, circles, discs, flat stampings, bars and rods, angles shapes and section, tubes, wire, cable, foil (whether backed with other material or not), flakes, granules, scrap and old metal, aluminium and aluminium-alloy waste or dross.

The Order comes into operation on the first of this month, but goods covered by the Order which are proved to the satisfaction of the Customs authorities to have been dispatched to the United Kingdom before the Order came into force will not require a licence.

The object of the Order is to assist in regulating the supply of aluminium alloys and aluminium scrap in the forms listed above so that the needs of the Services are satisfied, the export trade is maintained as far as possible and metal is available to produce certain essential goods for home industries, while limiting for exchange reasons the import of aluminium in these forms for non-essential purposes. While the granting of licences will depend on the circumstances of each case, and the conditions ruling at the time, applications to import such materials for the manufacture of goods for export will generally be allowed.

As no licences will be issued for the import of foil, which is defined as sheet, strip, etc., not exceeding 0·006 in. in thickness, applications for licences to import sheet and strip should accordingly specify thickness.

Directions for Obtaining Licences

(i) Licences will be issued by the Import Licensing Department of the Board of Trade on the recommendation of the Aluminium Controller, Ministry of Supply.

(ii) Application for import licences must accordingly be submitted in duplicate direct to the Aluminium Controller, Ministry of Supply, Raven Hotel, Shrewsbury, Shropshire. Application forms may be obtained from the Import Licensing Department, Board of Trade, 25, Southampton Buildings, Chancery Lane, London, W.C. 2, and the offices of H.M. Collectors of Customs and Excise. The direction at the head of the Application Form, that it should be forwarded to the Import Licensing Department, should be ignored.

(iii) After the application has been examined by the Aluminium Controller he will pass it to the Import Licensing Department, who, in approved cases, will issue and send the licence direct to the applicant.

(iv) It will greatly expedite the issue of licences if importers will state on the Application Form (*a*) the maximum c.i.f. value of each item; (*b*) the maximum quantity of each item expressed in those units which will subsequently be quoted on the Customs Entry; (*c*) the actual consignor, and not his agent, in the United Kingdom. It is essential that each application should refer to only one consignor and one country of consignment.

(v) Each licence has a currency of three calendar months. It is accordingly permissible for importers, if they so prefer, to include in one application the consignments which they expect will arrive during the three months following the date of application. The licence will, however, have to be presented for the clearance of each consignment.

(vi) Licences will be issued in the name of the actual importer only. For this purpose the importer is deemed to be the owner or other person for the time being possessed of, or beneficially interested in, the goods at and from the time of their importation until they are delivered out of the charge of the Officers of Customs and Excise.

(vii) Importers in doubt whether or not goods need an Import Licence, or are liable to duty, are advised to consult an Officer of H.M. Customs and Excise.

The Manufacture of Pig Iron in America

By William A. Haven

The primary purpose of this paper, which is to be presented at the May Meeting of the Iron and Steel Institute, is to describe the designs, equipment and practices which characterise practically all modern American blast furnaces, despite some great differences in the nature of the raw materials used in the principal producing districts. Some data given on the iron ores of the Lake Superior district, dealing with chemical qualities, iron content, benification, reducibility, physical characteristics, output, etc., the transportation of ores, and also data on coking coals and coke were prepared especially for members of the Institute who were to have attended the Autumn Meeting of September,* 1938. *Other information of special interest to blast-furnace operators has since been added, and in its present form can be regarded as a valuable contribution to knowledge on the manufacture of pig-iron. In this article the main practical aspects of the paper are given in a very condensed form.*

THE principal pig-iron producing districts, with one exception, are located along an imaginary line which extends from Monterey, Mexico, to Sydney, Nova Scotia, a distance of about 2,700 miles. These districts, which in addition to Mexico and Nova Scotia include Southern or Alabama district, Rocky Mountain district, Eastern New York and Pennsylvania district and Mid-Western district, are briefly reviewed. It is noteworthy that a single stack at Monterey, of 300 tons daily capacity, is the only pig-iron producing blast furnace in Mexico. Iron ore—a hard, high-grade hæmatite—is plentiful, and is obtained from the nearby State of Durango; good coking coal is obtained from Sabinas, about 150 miles from Monterey. In Nova Scotia the ore used is exclusively Wabana from Newfoundland, a dense, hard hæmatite, high in silica but containing no lime, and about 0·90% phosphorus. Nova Scotia coal is too high in volatiles to be of good quality for coking alone in by-product ovens. The largest of the Sydney furnaces, a stack of 18 ft. 3 in. × 89 ft. in size, produces over 500 tons daily, with less than a ton of coke per ton of pig iron on a straight ore burden. Similar conditions to those at Sydney prevail in the Birmingham, Alabama, district, where the principal ores are also hard, high-phosphorus hæmatites. The ores are of much lower grade but practically self-fluxing, so that the fuel requirements per ton of pig iron are about the same. Practice, in recent years, has been greatly improved by crushing the ore to smaller sizes. In Provo district, in the Rocky Mountain State of Utah, the hæmatite is also hard and the coke available very soft, so that early operations were difficult, but by crushing, grading the ore by size, and charging the various sizes separately, the coke consumption per ton of pig iron produced has been reduced from 2,500 lb. to about 1,750 lb., and the furnace output has been greatly increased. Another pig-iron producing district in America is that of the magnetite ores in Eastern New York, Eastern Pennsylvania and New Jersey. Although remote from soft coal supplies, plants in this district have been put on a sound economic basis by improvements in methods of ore dressing and in sintering of the fine, heavy concentrates. Some plants are using 100% sinter with complete success. It should be noted that the sinter is richer and of better structure than that made from flue dust, or from a mixture of flue dust and soft ores.

By far the greater part of American pig iron, however, is manufactured in a region which depends for its raw materials upon the Central Appalachian coal-fields and the iron-ore deposits of Northern Michigan, Wisconsin and Minnesota. This is the Mid-Western district which accounts for about 80% of the total in a normal year. It includes not only the great producing centres of Pittsburgh and Chicago, with their super-plants of Homestead and Gary, but also the districts of Cleveland, Buffalo, Detroit and the Ohio River Valley, in each of which are plants the annual productive capacity of which is measured in millions of tons. The region may be defined as that encircled by the Allegheny Mountains, the Great Lakes, and by the Ohio and the Mississippi Rivers. In this area

*Preprint, published by the Iron and Steel Institute for the May Meeting, 1940.

Fig. 1. — Aerial view of the Gary Works of Carnegie-Illinois Steel Corporation which includes the world's largest pig-iron producing plant.

have been felt the full effects of the unusual combination of economic, geographical and metallurgical conditions which American methods of pig-iron manufacture and the American type of blast furnace have been developed to meet.

Some of the plants in this region are situated very close either to the middle Appalachian coal-fields or to the Lake Superior ore deposits. At the one extremity will be found Johnstown, Pennsylvania, where the Cambria plant of

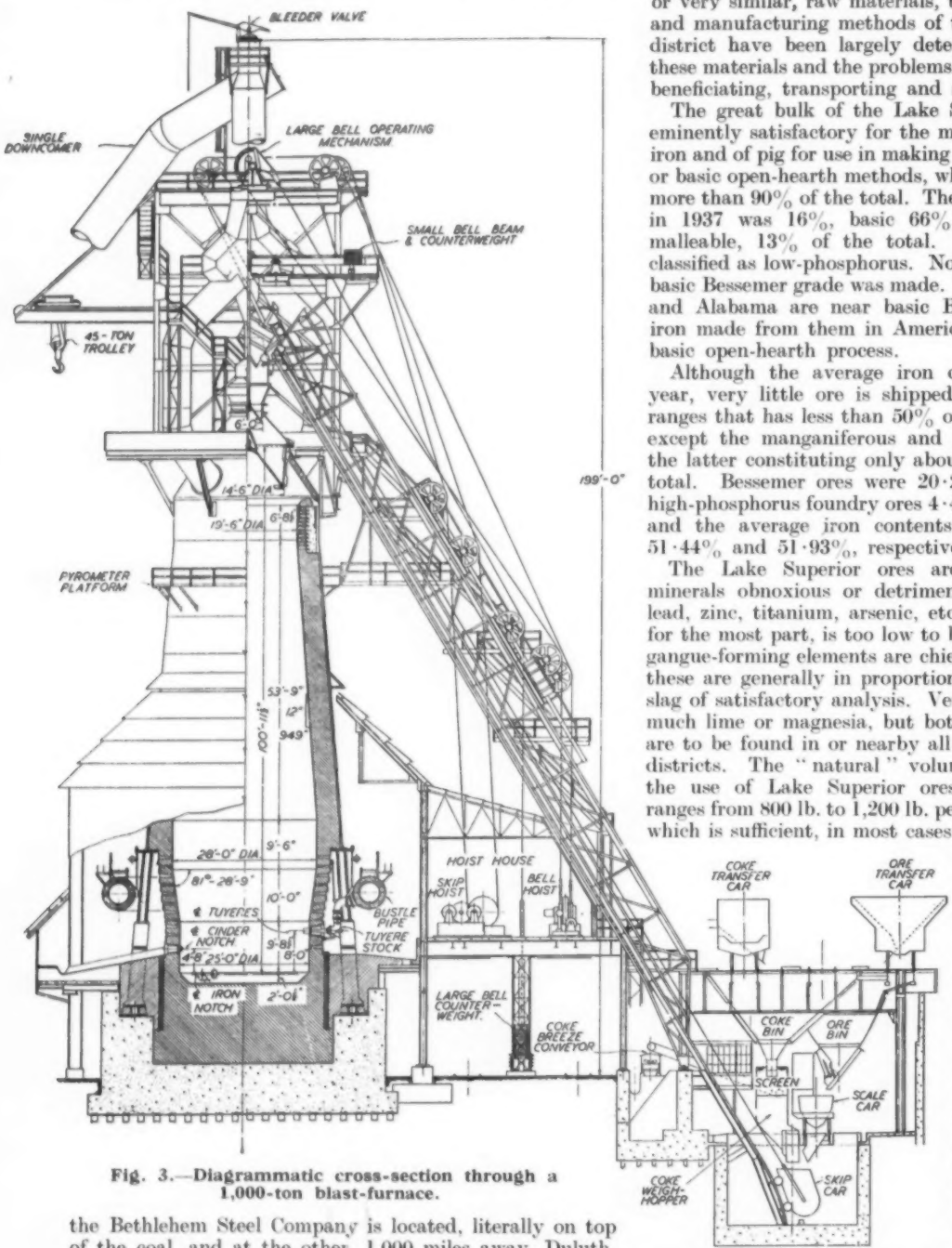


Fig. 3.—Diagrammatic cross-section through a 1,000-ton blast-furnace.

the Bethlehem Steel Company is located, literally on top of the coal, and at the other 1,000 miles away, Duluth, which is, figuratively at least, on top of the ore. The freight charges on coal at Johnstown are negligible, but on ore amount to approximately $6·00 per ton of pig iron, while at Duluth freight charges on ore are only $1·75, but on the coal about $4·25 per ton of pig iron. The transportation charges on ore and coal combined, therefore, are about the same in both cases.

Plants between these points are situated alongside or near water-courses, principally the Ohio River and its tributaries, or one or another of the Great Lakes, from which are derived relatively cheap transportation for either ore or coal, or for both. These geographical features do not completely determine the desirability of the location for pig-iron manufacture, since the cost and availability of scrap suitable for blast-furnace use and the proximity of the producing plants to the markets for pig iron and for blast-furnace by-products are other determining factors. But since all the plants of the Mid-West have had the same, or very similar, raw materials, the constructional features and manufacturing methods of the entire industry in this district have been largely determined by the nature of these materials and the problems incidental to their mining, beneficiating, transporting and smelting.

The great bulk of the Lake Superior ores is, however, eminently satisfactory for the manufacture of foundry pig iron and of pig for use in making steel by the acid Bessemer or basic open-hearth methods, which, in America, represent more than 90% of the total. The Bessemer pig-iron output in 1937 was 16%, basic 66%, and foundry, including malleable, 13% of the total. The remaining 7% was classified as low-phosphorus. No iron, strictly speaking, of basic Bessemer grade was made. The ores of Newfoundland and Alabama are near basic Bessemer quality, but pig iron made from them in America is all converted by the basic open-hearth process.

Although the average iron content is declining each year, very little ore is shipped from the Lake Superior ranges that has less than 50% of iron in the natural state except the manganiferous and so-called siliceous grades, the latter constituting only about 3·5% and 1·9% of the total. Bessemer ores were 20·2%, basic ores 70%, and high-phosphorus foundry ores 4·4% of the total shipments, and the average iron contents of these were 54·66%, 51·44% and 51·93%, respectively.

The Lake Superior ores are surprisingly free from minerals obnoxious or detrimental to smelting, such as lead, zinc, titanium, arsenic, etc. Their sulphur content, for the most part, is too low to be a serious problem. The gangue-forming elements are chiefly silica and alumina, and these are generally in proportions to form a blast-furnace slag of satisfactory analysis. Very few of the ores contain much lime or magnesia, but both limestone and dolomite are to be found in or nearby all of the pig-iron-producing districts. The "natural" volume of slag resulting from the use of Lake Superior ores and Appalachian coals ranges from 800 lb. to 1,200 lb. per ton of pig iron produced, which is sufficient, in most cases, to absorb the amount of sulphur which these materials contain.

An aerial view of Gary Works, which includes the world's largest pig-iron producing plant, with 12 modern blast furnaces, is reproduced in Fig. 1. This shows a typical arrangement for lake-front plant, with docks, fast unloaders, reserve stock, piles for ore and limestone, and stocking and reclaiming bridges. Fig. 2 shows an elevation of a typical blast-furnace plant located on the water-front; a diagrammatic illustration of a 1,000-ton blast furnace, in Fig. 3, indicates some of the important features in design; Fig. 4 illustrates a plant with three furnaces, in which a comparison can be made between the modern 1,000-ton furnace and the older one of 500-tons capacity. A view of a modern 1,000-ton furnace, from the cast-house side, is shown in Fig. 5.

Much of the ore received either in vessels or in cars during summer months goes directly into the charging bins to avoid rehandling. The ore-storage yards, contrary

to what seems to be occasionally believed, are of little value for blending materials, because, in reclaiming, the ore bridges cannot be operated in a manner to offset dependably the effects of the segregation of coarse and fine materials. As a matter of fact, because of these segregation effects, the operation of the furnaces will sometimes vary considerably during the months of the reclaiming period, from December to April. The finer materials from the top and centre of the piles predominate in the ore reclaimed during the early winter months and the coarser ones during the springtime. Freezing of the piles during severe winter weather adds further difficulties to reclaiming the materials in a uniformly proportioned manner. Since provisions must be made for six months' furnace operations, the amount of storage required for each 1,000 tons daily blast-furnace capacity is about 350,000 tons. The facilities for storage are generally large rectangular yards, all parts of which can be reached by travelling-bridge-type cranes.

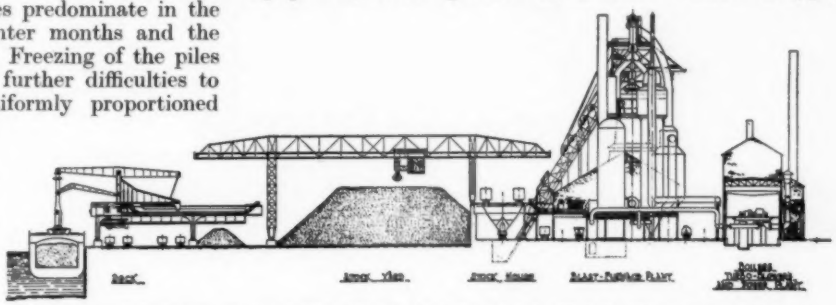


Fig. 2.—Elevation of a typical blast-furnace plant located on a water-front.

Delivery of coke to the furnace plant is preferably by belt conveyers if the ovens are not too far away. When serving only one or two furnaces the belt system can be carried to the coke-charging bins, but for a large group of furnaces distribution into charging bins by transfer cars makes for more flexible working conditions and clean-cut design on top of the bin system. Central coke bins, steep-sided and of comparatively small capacity, to avoid dust accumulations, discharging into stationary weigh-hoppers or directly into the furnace skips, are now almost always used.

The amount of storage capacity for ore in bins is influenced by the number of grades to be handled, but in modern plants the total is generally for about one-and-a-half days' furnace consumption, say 14 bins at 250 tons capacity each. The charging floor of modern American stock houses, for purposes of accessibility, ventilation, light and other desirable working conditions, are at or near yard level. The stock-house structure, therefore, must generally be designed for the purpose of supporting both bins and tracks and one end of the ore bridge, as well as to act as a retaining wall as to act as a retaining wall for the ore-storage piles. Fig. 6 shows a modern blast-furnace stock house with a scale-car and bins of the Baker suspension type.

Bottom Charging Equipment

The Lake ores, while not ordinarily excessively sticky, are often far from being free-running, and the amounts that must be handled are, of course, very large, amounting to as much as 2,500 tons per day for a single furnace. Equipment for charging such tonnages of ore, along with the required coke, limestone and other raw materials, with a single man per turn, is one of the outstanding accomplishments of American blast-furnace design. The bins are made steep-sided, about 52½°, completely freed of internal stiffening diaphragms, and provided with gated openings that are continuous from end to end. The individual gates are small, making manual operation easy. Scale- or weigh-cars for the larger furnaces are generally of the double-compartment type, each hopper having a volume capacity at least equal to that of the skip cars, generally about 180—200 cub. ft., making it possible to draw a full charge of ore while the coke is being hoisted. Automatic recording devices on the cars check the accuracy of the weighing.

Coke is drawn from bins located centrally above the skip by motor-operated feeders, which also function as screens, into weigh-hoppers. Drawing and weighing the coke, dumping the weigh-hoppers through drop-doors into the skips, and the complete charging, hoisting and top-charging operations are automatically performed in prearranged sequence by motorised apparatus under the control of electrical devices, properly interlocked. After a charge or skip of ore is hoisted, the master control switch of the automatic charging system is thrown by the scale-car operator, who can then depart on a trip for another charge of ore while the skips are being hoisted and the bells being dumped by his mechanical helpers.

For hoisting and top-charging, so-called hand-filling has practically disappeared. Of the automatic mechanical equipment, the single bucket, called the Neeland type, which is in such general use in Europe, has steadily lost ground in favour of the double skip. The advantages of the latter are believed to be simplicity of design and lower first cost, greater economy in operation and upkeep, greater dependability for continuous service and, particularly, greater filling capacity, a matter which has become of paramount importance with the increased output of the stacks. It must be admitted, however, that without a satisfactory distributing device on the furnace top to correct its inherently faulty distribution of stock, this almost universal application of skip filling would scarcely have been possible. For the problem of distribution, however, the McKee revolving top furnished a complete solution, and has been developed into a practically trouble-free piece of equipment.

For dumping the bells, electric bell hoists, since their advent, have generally had first preference, although occasionally equipment operated by steam or air cylinders is still used for economy in first cost. Some of this equipment has the objectionable characteristic of depending upon gravity for the opening of the large bell. A new device, called the Martin rig, provides positive opening for the large bell, and has also made possible certain other desirable changes, amongst them the elimination of the large bell beam, which, in its modern dimensions, has become clumsy and somewhat hazardous.

Although furnaces of similar designs are coming to be built in all countries, it seems reasonably correct to identify the type of construction used for the blast furnace itself in the United States as American, for it embodies certain outstanding characteristics, including great size and structural strength, that were developed particularly to meet American conditions.

The departure from English and European types of furnaces seems to have started with the rapidly increasing demand for pig iron and the use of the fine, soft Mesabi ores which began about 1890. It may be said to have culminated, at least for a time, in the 1,000-ton furnace, about 1930. In these 40 years the annual requirement for pig iron of the United States had grown from 9,000,000 to 40,000,000 tons.

The modern American furnace is for the most part the result of improvements that were developed to solve the operating difficulties of those years. The furnace shells were increased in thickness from ¼ in. to 1¼ in. The Kennedy sloping top or cone ring was invented to stiffen the top section, and for the loosely fitted combination of hopper and lip ring was substituted a single hopper tightly bolted to the cone casting, to which, in turn, the cone ring was riveted. The use of cast iron for hoppers and bells and other parts exposed to shock and strain was discontinued in favour of steel. American furnaces, it should be kept in

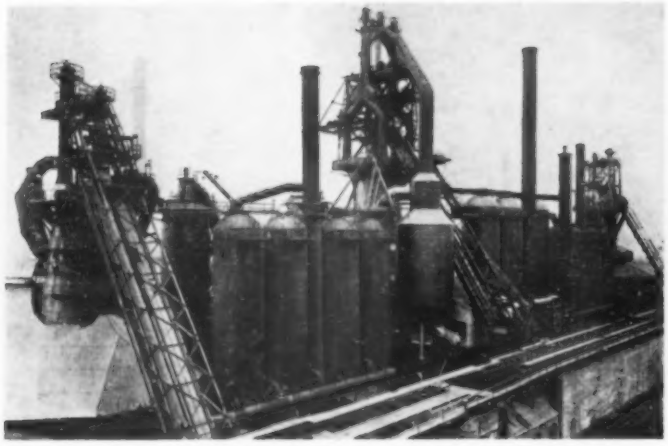


Fig. 4.—Plant of three blast furnaces of the Great Lakes Steel Corporation. Note the modern 1,000-ton furnace.

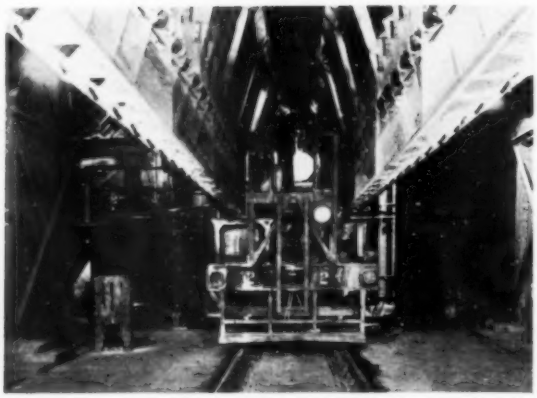


Fig. 5.—Modern 1,000-ton blast furnace of the Indian Steel Company, as seen from the cast-house side.

mind, are designed to operate normally on from 20-in. to 40-in. water gauge of top-gas pressure.

For the protection of the hearth and bosh, the principal development was in the method of cooling, the use of external sprays giving way entirely to that of cooling plates laid in the brickwork. Protection of the shell above the mantel has been achieved by similar means when deemed necessary, that is, by the circulation of water in totally enclosed cooling plates, generally placed horizontally within the brickwork. In both the bosh and inwall these plates also serve to maintain the initially established interior dimensions of the lining much more effectively than was previously possible.

In the campaign to make the furnace lining a more lasting one, the brick-manufacturing companies have played an important part in the development of refractories that are not only better suited chemically for specific purposes, but which are also remarkably accurate and uniform as to size and shape of each piece of brick. Measured by years in blast, some English furnaces have records surpassing any in the States, to our knowledge, but for tonnage output the American stacks, with many runs of from 1,000,000 to 2,000,000 tons, and a maximum of about 2,500,000 on a single lining, are probably record holders for performances of this sort.

Furnace Dimensions

In their interior dimensions American furnaces are characterised by large hearth and top diameters, great overall heights, and low, steep boshes. The dimensions of three 1,000-ton furnaces, designed and built by the author's firm in 1937–38, are indicative of the comparative uniformity of ideas with regard to lines in the three rather widely separated localities of Cleveland, Detroit and Chicago. Twenty-five feet of hearth diameter and 100 ft. of height have come to be considered almost standard requirements for the output of 1,000 tons per day from Lake ores, but recently there has been a tendency to still greater heights. The Republic Steel Corporation's Youngstown furnace No. 2 was rebuilt in 1938 to 25 ft. 6 in. in hearth diameter by 105 ft. high. This year a furnace 108 ft. high, having a 27-ft. hearth, will be built, and the author has recently proposed overall dimensions of 110 ft. × 30 ft. for a client who was interested in building the largest unit possible without hazardous pioneering.

It is also worthy of note that furnaces of generous diameter and volume have been found satisfactory and desirable in other American districts and other countries where the iron ores have differed greatly from the fine materials used in the American Middle-West—with richer and coarser ores, as in Russia and India, and with leaner and coarser ores, as in the American Southern area. One is led to the belief that the construction of furnaces of the 1,000-ton or super 1,000-ton class would be especially well suited for smelting the lean English ironstones at reduced costs and with improved furnace practice generally.

Casting Facilities

The facilities for casting hot metal and flushing slag from the furnaces have had to be kept in step with the increased output of the stacks. The use of sand-runners, and particularly the practice of skimming "by hand," would be quite inadequate for handling single casts of several hundred tons in weight. The skimming trough and iron and slag runners are now all made up in permanent heavy iron castings. The trough is generally lined with fireclay and the runners with a mixture of sand and coke breeze. The Killeen skimmer, with various modifications, is used at all plants. Mud guns capable of stopping the tap-hole while the full blast pressure is on the furnace are considered essential.

Metal and Slag Handling

The tendency towards the adoption of large units is as pronounced with respect to auxiliary equipment as in the case of the stacks themselves. Thus, in the handling of hot metal the use of mixer-type ladles of up to 125 tons capacity has proved economical by reducing the scrap losses and making it possible to deliver hotter iron to the steel-works. By this means also it has been made feasible to transport molten metal unusually long distances, as between the Hamilton furnace and the Middletown Steel Works in Ohio, which are some 20 miles apart.

As to cold pig, there is no longer any casting in sand-beds in America, and the procedure of machine casting has been brought to a rather high degree of perfection. Not only are the pigs reduced to any desirable size, "piglets," but by improved methods the kish can be skimmed off and the pigs given a smooth, clean surface. Even the depth of chill has been reduced to satisfy certain users of foundry iron. All the big steel-making companies now produce merchant grades of iron as a fill-in, so that for some years there has been definitely a "buyers' market" in this trade.

For slag handling, ladles of about 400 cub. ft. capacity have been the practical maximum size, warping of the pots being the limiting condition. Self-dumping ladles of the air- or steam-cylinder type are universally used. The most economical means of handling slag in the hard form, and one that isolated furnaces frequently use, is to run the material directly into twin pits, from which it is recovered by steam- or electrically-driven shovels, or by overhead cranes, and loaded into railway cars or auto trucks. Thus, the cost of handling in ladles, which amounts to from 10 to 20 cents per ton of slag, is completely avoided. Having the pits alongside the furnace, however, is a nuisance from the standpoint of plant cleanliness, and is hardly to be recommended for large groups of furnaces, although pits used commonly by several furnaces, located

within a reasonably short distance of the plant, are probably productive of a better grade of slag for commercial uses than the high dumps so often seen in England.

Power Plants and Blowers

There are not many novelties in the features of American blast-furnace power plants, but they reflect the adoption without unreasonable delay of improved types of steam-raising, electric-generating and air-compressing machinery. The more-recent boiler installations range from 1,000 to 2,000 h.p. nominal rating in size, and are generally designed for the use of thoroughly cleaned blast-furnace gas as principal fuel and pulverised coal for auxiliary firing. The pressures commonly carried are 250 lb. to 400 lb., with 200° to 250° F. of superheat, and, depending upon the proportions of these fuels used, efficiencies of from 79 to 85% are obtained. The generation of primary electric current is generally at 6,600 v., and distribution at 220 v. a.c. and 230 v. d.c. Alternating current is now ordinarily used for all purposes except travelling cranes and skip-hoist motors. Practically all new blowing installations during the past 10 years have been steam-driven turbos.

Hot-blast Stoves

Stove shells to withstand the blast pressures mentioned are now ordinarily designed of about $\frac{5}{8}$-in. plates, either double-riveted in both horizontal and vertical seams, or welded. Only three stoves of modern design are needed, even for the largest furnaces, it being possible to secure 200,000 sq. ft. of heating surface in a single 100 ft. × 24 ft. stove, and this may be considered about the maximum size for designs that are satisfactory in all respects. The preferred arrangement of hot-blast stoves in America is parallel to the stock house, and approximately on the centre-line of the furnace and the cast house. In plants with more than one furnace the stoves for each pair of furnaces are generally grouped in a single line.

Gas-cleaning Equipment

The cleaning of blast-furnace gas is a phase of pig-iron manufacture in the States, the development of which has probably lagged behind that of any other. Until 15 years ago equipment for thoroughly cleansing the gas, say, to less than 0·02 grain per cub. ft., was only found in a few plants where gas-blowing engines were used. These were all of the old drum Theisen type. The chief reasons for this backwardness was probably the costliness of the gas-cleaning equipment and its operation as compared with the value of the gas when calculated from the cost of its B.th.u. equivalent in the form of bituminous coal.

The situation began to change when the increased blast-volume requirements of the big furnaces stimulated the relining of hot-blast stoves with small checker work, and with the utilisation of blast-furnace gas for underfiring coke-ovens and in steelworks' furnaces. These measures called for thoroughly cleaned gas, and since their adoption has been rapid and widespread during the past decade, most American plants to-day have some facilities for final cleaning. Two methods are in common use—Cottrell precipitators, as built by the Research Corporation, and disintegrators of the usual types; the latter are seldom installed now unless surplus gas or other sources of cheap power are available. The precipitators are somewhat higher in first cost, but generally have a wide margin in their favour in respect of power consumption and total cost per unit of gas handled.

The American development of the electric precipitator is something quite different from either the Lodge-Cottrell or the German ones, inasmuch as the method includes the thorough scrubbing and cooling of the gas prior to precipitation, the precipitators themselves operating on cold gas saturated with moisture and the dirt being precipitated and collected in the form of thin sludge. Primary washing is accomplished in towers with rain-making devices and hurdles of various types, and for the complete recovery of the dust that is removed, equipment for thickening the sludge and conditioning it for the sintering plant, or its return directly to the furnaces, must also be included.

Sintering and Sintering Plants

The sintering of flue dust is not so great a problem as in past years, because the production of it has been reduced to a small fraction of former amounts by improvements to blast-furnace designs, equipment and operating methods. Sintering plants that at one time were fully occupied with the agglomeration of flue dust are now at times idle or increasingly utilised for sintering fine ore. The flue dust that is being produced, however, is being more carefully recovered and conserved in both dry and wet forms. The finely divided carbon which it contains is a valuable contribution to the mixture when flue dust and ore are combined for sintering purposes.

Sinter made from a mixture of fine ore and flue dust is generally of a better quality than that made of flue dust alone, and in sintering plants recently put down consideration has nearly always been given to the proper preparation and handling of both of these materials. The Dwight-Lloyd and Greenawalt systems continue to be the most favoured methods of agglomeration, and both types of equipment have been considerably improved in details of design and construction.

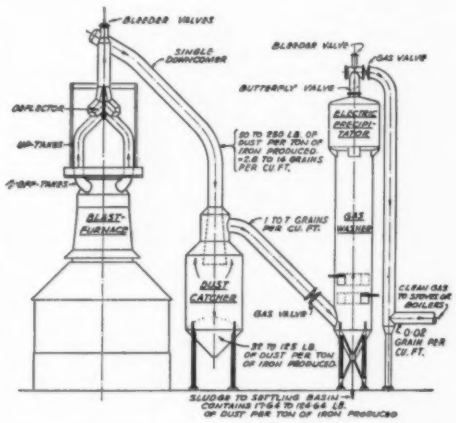

BLEEDER VALVES
SINGLE DOWNCOMER
BLEEDER VALVE
GAS VALVE
BUTTERFLY VALVE
DEFLECTOR
ELECTRIC PRECIPITATOR
50 TO 250 LB. OF DUST PER TON OF IRON PRODUCED = 1·2 TO 16 GRAINS PER CU. FT.
BLAST-FURNACE
1 TO 7 GRAINS PER CU. FT.
GAS WASHER
DUST CATCHER
CLEAN GAS TO STOVES OR BOILERS
0·02 GRAIN PER CU. FT.
GAS VALVE
97 TO 195 LB. OF DUST PER TON OF IRON PRODUCED
SLUDGE TO SETTLING BASIN — CONTAINS 1764 TO 1944 LB. OF DUST PER TON OF IRON PRODUCED

Fig. 6.—Modern blast-furnace stock house of the Bethlehem Steel Company, showing scale-car and bins of the Baker suspension type.

The author concludes with a brief discussion on American blast-furnace practice in which he deals with the more important developments since 1933, when he discussed the same subject in a paper before the Iron and Steel Institute. Methods of blast-furnace operation have become more uniform as a result of crushing all ores to smaller sizes and the adoption in other districts of furnace lines and equipment that had been developed for the economical smelting of the fine Lake Superior iron ores. All new furnaces built since 1933 have been of the 1,000-ton class, and the rebuilding of old stacks to larger sizes has continued. The author claims that this procedure has been justified not only by increased output per stack, and consequent reductions in the "cost above raw materials," but by markedly improved results metallurgically. Coke consumption rates have been lowered, the dust losses have been curtailed, and pig iron quality has been improved in analysis and uniformity. The larger furnaces have also shown a remarkable flexibility for satisfactory operation over a wide range of daily output.

Institute of Metals

THE thirty-second annual general meeting of the above Institute will be held at 4, Grosvenor Gardens, London, S.W. 1, on March 6, 1940, at 2-30 p.m. The meeting will be of a formal character and will be held for the purpose of considering the report of Council, the Treasurer's report, the election of officers and members of Council for the year 1940-41, and for transacting the ordinary business of the Institute. No papers will be presented or discussed.

Hypersilid—A High-Silicon Acid-Resisting Alloy

THE use of high-silicon-alloy cast iron, on account of its excellent corrosion-resisting properties, is well known in the chemical industries. Alloy cast irons of this type usually have a silicon content of 14 to 16% and are marketed under a variety of trade and proprietary names. The chemical composition of a few of these different materials, obtained from published data and in some cases from analyses made in Bradley's Research Laboratories, are assembled in Table I.

TABLE I.
CHEMICAL COMPOSITION.

Trade Name.	Total Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Nickel.
	%	%	%	%	%	%
Duriron	Under 1	14·25—14·75	0·25 approx.	0·03	0·1 approx.	—
Ironac	Under 1	13·0 approx.	0·8	0·05	High	—
Tantiron	0·2 to 0·6	14 to 15	0·25 to 0·35	0·05	0·05 approx.	—
Metillure	0·6	16 to 17	0·9	0·02	0·2 approx.	—
Elianite, I	—	15	0·6	0·05	0·05 approx.	—
Elianite, II	0·8	15	0·5	0·03	0·05 approx.	2·0
Thermisilid	0·56	15·04	0·44	0·010	0·59	—
Corrosiron	0·2 to 1·3	12·0 to 15	0·25 to 0·35	0·05	0·2	—

TABLE II.

	Hydrochloric Acid.		Nitric Acid.		Sulphuric Acid.	
	Normal.	Concentrated.	Normal.	S.G. 1·20.	Normal.	10%.
Wrought iron	0·1416	0·2217	0·1263	0·6399	0·1452	0·3610
Mild steel	0·0850	0·1812	0·1154	0·5858	0·1052	0·1032
Cast iron	0·1340	0·3280	0·1022	0·1300	0·1364	0·1158
Stainless steel	0·0638	0·1799	0·0111	Nil	0·0871	0·1126
High-silicon cast iron	0·0007	0·0009	0·0003	0·0008	0·0001	0·0006

TABLE III.

	Water.	Sea-water.	Vinegar.	33% Acetic Acid.	5% Citric Acid.	5% Ammonia Chloride.	1% Magnesium Chloride.
Wrought iron	0·0161	0·0036	0·0100	0·2023	0·1075	0·0084	0·0033
Mild steel	0·0150	0·0047	0·0032	0·1492	0·1458	0·1024	0·0036
Cast iron	0·0226	0·0040	0·1901	0·4819	0·1404	0·0101	0·0032
Stainless steel	Nil	Nil	Nil	0·0232	0·0422	0·0014	0·0018
High-silicon cast iron	0·0002	0·0005	0·0004	0·0003	0·0012	0·0003	0·0004

Another alloy of this type, known as Hypersilid, is manufactured by a new and special process developed in the Bradley Laboratories. The composition of this alloy is within the limits of the normal types of silicon-iron alloys as given in Table I, and the improvements effected by the Bradley process lie in the improved casting properties, soundness and strength of the final alloy.

The general physical properties of the iron-silicon alloys, in comparison with ordinary cast iron, are as follows:

	Ordinary Cast Iron.		High-silicon Acid-resisting Cast Iron.
Density	7·3 grs. per c.c.	..	6·5 grs. per c.c.
Melting point	1,150° C.	..	1,200° C.
Heat conductivity	10	..	8
Electrical resistivity	8	..	10
Contraction	$\frac{3}{32}$ in. per ft.	..	$\frac{5}{32}$ in. per ft.

Alloy cast irons of this composition are highly resistant to a wide variety of corrosive media. They are practically unattacked by sulphuric, nitric, hydrochloric or acetic acids, concentrated or dilute, hot or cold. They are, however, attacked by alkalies in a manner exactly similar to ordinary cast iron. Some comparative results of the behaviour of various materials, including high-silicon cast iron, under various corroding influences have been published by Dr. Hatfield.* These results are conveniently extracted in Tables II and III. In Table II the results are given from tests with mineral acids after a period of 24 hours' immersion at an initial temperature of 15° C., and Table III gives the results of tests extending over a period of one month. The corrosion value is expressed as the loss in weight in milligrammes per square centimetre of surface.

In these various media high silicon cast iron gives excellent results. It is not recommended for use with bromine, fused alkalies, hydrofluoric or hydrofluorosilicic acids when concentrated, hot concentrated ferric chloride, chlorides of sulphur, caustic solution, sulphurous acid and certain sulphates. These alloys have approximately the same specific gravity as cast iron and a slightly lower electrical conductivity. The coefficient of expansion is higher, being $1·565 \times 10^5$ as compared with $0·672 \times 10^5$ for ordinary grey iron. In a like manner the thermal conductivity is lower, being 0·1250, as compared with 0·1430 (silver = 1). The outstanding disadvantage of this alloy is its excessive hardness and brittleness. It is essentially a white iron and is unmachinable by ordinary methods. In addition, it is brittle and has a low-breaking strength value. Great care in the design of apparatus is necessary on this account when using this material.

The Engineer, December 15, 1922.

Lead and Zinc Production in Canada, 1939

CANADIAN lead production during the past year totalled 391,499,038 lb., valued at $12,375,000, a decrease of 7% in quantity and of 12% in value, as compared with 1938. Over 97% of the total Canadian lead production comes from the mines of British Columbia, of which by far the largest producer is the Sullivan, which is owned by the Consolidated Mining and Smelting Co. of Canada, Ltd., at Trail. Production is also recorded in ores exported from the Yukon Territory and Nova Scotia. The price of lead on the London market, transposed to Canadian funds, averaged 3·161 cents per lb. during the year.

More zinc was produced than in any previous year, and output amounted to 394,955,897 lb. This total was made up from the refined zinc made at Trail, British Columbia, at Flin Flon, Manitoba, and zinc in ores exported. The price of zinc for the year averaged 3·055 cents per lb., London prices converted to Canadian funds, and which gave a total value of production of $12,066,000.

Low Lead-Silver Alloys for Bearings

Further investigations on lead-silver bearing alloys are discussed. They were carried out to determine whether the properties of such alloys are suitable for high-speed engine bearings. The bearings were produced by simultaneous disposition of silver and lead by electrolysis. Relative seizure resistances are given.

SUITABLE alloys for bearings for high-speed engines, such as are used in aircraft, are of great importance, particularly at the present time. Considerable and useful research work on the silver-rich bearing alloys has been carried out by R. W. Dayton, and the results of such work were discussed in a paper to the American Institute of Metallurgical and Mining Engineers, a summary of which was given in METALLURGIA.[1] Further researches on these alloys have been carried out by the same investigator, and the results obtained are dealt with in a contribution in a recent issue of *Metals and Alloys*.[2] In these last experiments some of the properties of a series of alloys containing 0 to 5% of lead are determined in order to find whether such properties show the lead and silver alloys to be suitable for high-speed engine bearings.

TABLE I.

RELATIVE SEIZURE RESISTANCES OF SILVER-LEAD ALLOYS.

Lead. %	Specimen Condition.	Relative Seizure Pressure.				
		Polished Shaft.		Ground Shaft.		
0·02	As Cast	110	—	50	—	—
	As Cast-corrosion Tested	—	—	—	—	75
	Annealed	—	125	—	55	—
	Anneal-corrosion Tested	—	—	—	—	90
0·98	As Cast	125	—	80	—	—
	As Cast-corrosion Tested	—	—	—	—	105
	Annealed	—	110	—	80	—
	Annealed-corrosion Tested	—	—	—	—	105
1·55	As Cast	120	—	80	—	—
	As Cast-corrosion Tested	—	—	—	—	125
	Annealed	—	100	—	90	—
	Annealed-corrosion Tested	—	—	—	—	120
2·96	As Cast	110	—	85	—	—
	As Cast-corrosion Tested	—	—	—	—	125
	Annealed	—	115	—	100	—
	Annealed-corrosion Tested	—	—	—	—	125
3·68	As Cast	130	—	135	—	—
	As Cast-corrosion Tested	—	—	—	—	145
	Annealed	—	125	—	105	—
	Annealed-corrosion Tested	—	—	—	—	140
4·68	As Cast	130	—	110	—	—
	As Cast-corrosion Tested	—	—	—	—	140
	Annealed	—	125	—	135	—
	Annealed-corrosion Tested	—	—	—	—	140

Six silver alloys, containing 0 to 5% of lead, were made from double-refined silver, 99·995% purity and pure test lead. Two bars, 2 in. long, $\frac{3}{4}$ in. diameter, were cast from each alloy in warmed graphite moulds. One bar was tested as cast, and the other, after annealing for two days at 290° C., followed by two days annealing at 191° C. The higher annealing temperature was selected as being slightly below the eutectic temperature of the alloys (304° C.), at which temperature the solid solubility of lead in silver is at a maximum, so as to destroy the cast structure as much as possible by dissolving the lead. By reannealing at the lower temperature, the lead was partly reprecipitated in a form different from which it was originally. The object of the annealing treatment was to determine the influence which change of structure had on the bearing properties, corrosion resistance, and physical properties of the alloys.

The seizure resistance of the alloys was determined on the Amsler wear-testing machine, previously described, as this method of testing material as a bearing was found to determine the maximum load at which a test bearing could be run without seizure, and to be in accord with service results. As it had been previously found that if the seizure resistance against a ground shaft is much lower than against a polished one, the bearing metal is not a reliable one; tests were made using both ground and polished shafts. The bearing metal with a high seizure resistance equally good with either ground or polished shafts is considered the most satisfactory. Each alloy was tested in four different conditions, and the relative seizure resistance values obtained in terms of a standard alloy containing 71% copper, 28% lead, 1% silver, which is regarded as 100 on the arbitrary seizure-pressure scale, are given in Table I, together with the compositions of the various alloys.

The results obtained for polished shafts show that lead additions do not appreciably change seizure resistance, but with ground shafts lead additions are necessary to improve the reliability of a bearing, and that about 3·5% of lead is required before the alloy performs as well against ground shafts as against polished shafts. There is no consistent difference between the as-cast and annealed specimens. The corrosion-tested specimens, however, are in every case superior to the same specimens before corrosion testing, and this is attributed to the eight-day annealing at 172° C., which was part of the corrosion tests. Silver-lead alloys containing more than 3·5% lead are extremely seizure resistant being nearly 50% better than the standard copper-lead alloy.

Under certain conditions copper-lead alloys and cadmium-base alloys fail in bearing service as a result of corrosion, due to compounds which are corrosive to lead and to cadmium developing in the oil after extended periods of use, and resulting in portions of the bearing metal lining being eaten away. Since lack of corrosion resistance is a serious defect in bearing metals, the silver-lead alloys were tested for this property at 172° C. for eight days by submerging in an oil-bath, to which 1% of oleic acid had been added and through which air was bubbled. During immersion the specimens were rotated so that the faces used for the bearing tests travelled through the oil at a speed of about 100 ft. per minute. There was no corrosive attack on any of the 12 specimens during the test period, and the bearing properties of all the alloys, as shown by their relative seizure resistances, was improved, indicating that treatment in corrosive oil had not deleterious effects.

Bearings in service sometimes fail by fatigue-cracking, but pure silver bearings are not subject to this type of failure. Three types of physical tests, Brinell hardness, shear strength, repeated blow impact tests, were applied to the silver-lead alloys to find whether lead additions weakened or strengthened silver. In those tests the Brinell hardness was found to increase from 24 to 25 for pure silver to 33 to 34 for the 3% lead-silver alloy; the shear strength was at a maximum with about 1·5% of lead, and did not drop much with further additions of lead, and repeated impact tests showed the silver to be hardened by lead additions up to about 3%. Since it was found from these tests that the strength of lead-silver alloys was greater than that of pure silver, it is assumed that there is no danger of fatigue-cracking of silver-lead bearings.

1 *Metallurgia*, 1939, Vol. 19, No. 113, p. 190.
2 *Metals and Alloys*, 1939, Vol. 10, No. 10, pp. 306–310 and 324.

Pure silver bearings are produced commercially by pouring molten silver into a clean, rotating, steel shell, followed by slow cooling, when a very firm bond of silver to steel is obtained. The same method was tried for the bonding of silver-lead alloys, but without success, as too weak a bond was obtained. The diffusion of lead into a silver bearing, so that the running face of the bearing would be a silver-lead alloy, was thought to offer a solution, but experiments, both at 815°C. and at 230° C., which is below the eutectic temperature, showed that diffusion was not a practical means of preparing such bearings. At the higher temperature intercrystalline brittleness resulted, and at the lower temperature diffusion was too slow.

TABLE II.

SEIZURE RESISTANCE OF VARIOUS BEARING METALS AS DETERMINED ON THE PRATT AND WHITNEY ENGINE-TYPE OF BEARING TESTER.

Bearing.	Approximate Composition.	Speed to obtain Seizure. R.P.M.	Bearing Pressures at Seizure. Lbs./sq. in.
Silver Bearing ..	99·5% Ag, Remainder Cu.	2,650	3,410
Bronze	25% Pb, 3% Sn, Remainder Cu.	3,000—3,200	4,380—4,980
Silver-lead Plated 0·006 in.....	3·62% Pb, Remainder Ag.	3,400	5,620
Silver-lead Plated 0·0025 in.	3·41% Pb, Remainder Ag.	3,700	6,650
Bronze*	1% Ag, 28% Pb, Remainder Cu.	3,950	7,590

* This Bronze is not sufficiently fatigue-resistant for continuous service.

The most satisfactory method of obtaining well-bonded bearings of silver-lead or steel was found to be by the simultaneous deposition of silver and lead by electrolysis. The electroplating bath used was a silver-cyanide bath containing lead as acetate. With such a method it was possible to obtain alloys of the desired composition whose bearing properties were as good as those thermally prepared, and which were extremely adherent. It was also thought from the structure of such deposited alloys that their physical properties would be better than the cast alloys, because of their lack of dendritism.

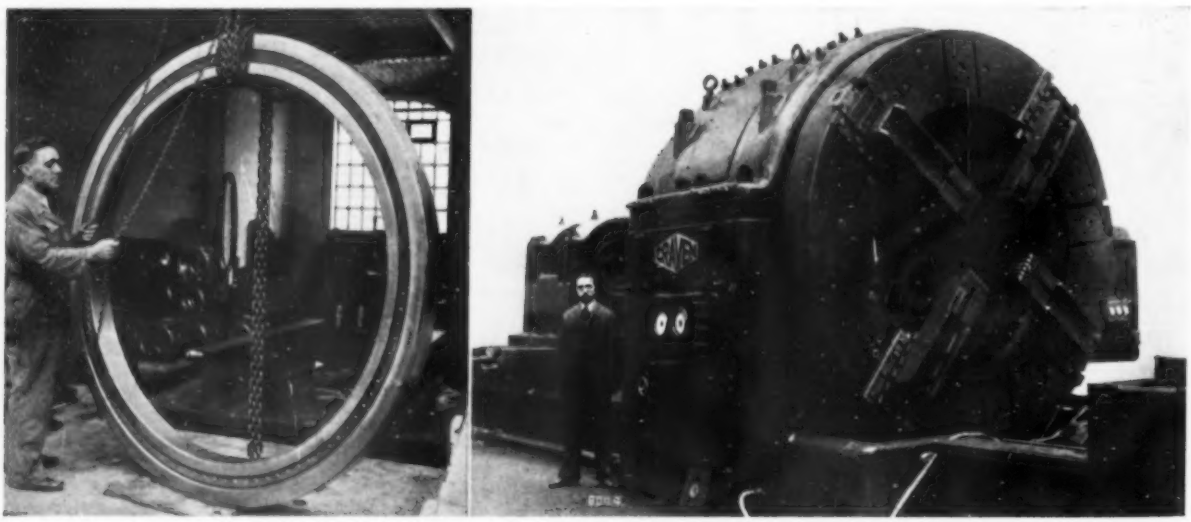
Subsequent to the laboratory tests on the silver-lead alloys, practical tests were made on a machine which simulated the action of an engine. Two full-size master-rod bearings were bored oversize and electroplated with an excessive thickness of a silver-lead alloy, given an annealing treatment of 5 hours at 230° C., followed by four days at 175° C., then bored to the correct size. These bearings were then tested against a finely ground shaft of carburised steel in a bearing testing machine in which the test bearing was loaded by the inertia of a revolving eccentric weight. The relative seize resistances of these bearings compared with other bearings are given in Table II, and show very positively that the bearing characteristics of silver have been greatly improved by the presence of lead.

Fatigue Strength of Crankshafts

THE Research and Standardisation Committee of the Institution of Automobile Engineers is carrying out a research on the fatigue strength of crankshafts. The investigation is primarily concerned with the study of fatigue strength in bending of crankshafts for compression-ignition engines, since bending fatigue failures have been experienced in service. The information obtained is, however, proving of value in the design of all types of crankshaft.

Three machines are in use. These machines apply reversed bending moments to the specimens, which are usually multi-throw crankshafts, one throw being broken at a time. The deflection is applied through a variable throw eccentric, and is calibrated in terms of bending moments. Failure occurs across the web, the crack starting from a fillet, and the nominal stress figure is calculated in the ordinary way from the modulus of the area of fracture. The fatigue limit is determined on a basis of ten million repetitions.

A good deal of work has been carried out on these machines to study the fatigue strength of various designs of shaft in relation to the material employed. Recently, attention has been devoted more especially to various methods of surface hardening, including nitriding, chromium plating, etc. In addition, owing to the importance under war-time conditions of salvaging worn parts for further use, a study is being made of the effect of certain processes, such as metal-spraying, for building up crankshafts.



The large tapered roller bearing shown in the illustration on the left is one of four recently manufactured by Messrs. British Timkin, Ltd., for application to two large lathes, built by Messrs. Craven Bros., Ltd., for boring hollow tubes. In spite of the great dimensions of the bearing, which are 81½ in. × 67 in. × 5½ in., and the relatively light section of the components, it is manufactured to extremely fine limits of accuracy. The headstock of the machine on which these bearings are fitted is illustrated on the right.

ALUMINIUM INDUSTRY
A Practical Review
WORKING & FABRICATING ALUMINIUM & ITS ALLOYS

February, 1940 METALLURGIA Vol. XXI, No. 124

PRACTICAL ASPECTS OF WORKING ALUMINIUM AND ITS ALLOYS

IT is just about 30 years ago that Wilm discovered an aluminium alloy which could be hardened. He found that after quenching at 500° C. this alloy, which was named duralumin, hardened by merely standing at room temperature for several days. From then onwards, with gradually increasing impetus, intensive research has been carried out in practically all industrialised countries, which has led to great progress in the development of aluminium alloys. To-day, something like 800 aluminium alloys are available, from low-strength non-heat-treatable alloys to those having a tensile strength of nearly 40 tons per sq. in. in the fully heat-treated condition.

This striving to increase the range of aluminium alloys led to a rapidly growing consumption of aluminium. The increasing range of properties possible increased its field of usefulness, and almost every industry found a growing need for aluminium in one form or another. To-day, aluminium alloys are used for purposes which would have seemed unlikely a few years ago. In many instances these alloys have been used to displace steel, but, obviously, no change of this character should be made without a very careful consideration of the conditions of service and the relative merits of the rival materials.

Even to give a brief summary of the development and application of the principal aluminium alloys is unnecessary here, but a short reference to groups of alloys from the large number available will be of interest. An analysis of the principal alloys shows that the elements usually added in relatively large percentages, between 10% and 15%, are copper, silicon, magnesium, and zinc. Other elements which may be present in amounts up to about 2% are nickel, manganese and iron ; while very small quantities of titanium, chromium, antimony, cadmium, lead, bismuth, or cerium may also be present. These alloying elements are added in order to improve the mechanical properties of aluminium, or to modify certain properties which influence production operations. Although many elements are used for alloying purposes, aluminium alloys may be broadly grouped into those comprising aluminium-copper, aluminium - silicon, aluminium - magnesium - silicon, aluminium-magnesium, aluminium-zinc, and aluminium-manganese.

Probably the most outstanding reason for the progress in the use of aluminium is that associated with the development of modern transport—a development which has caused engineers to explore all avenues for reducing weight, and also metallurgists to search for new alloys and to improve existing ones. It is the development of aircraft that has given the aluminium industry its greatest impetus. In addition to low specific gravity and relatively high strength, many alloys have excellent ductility, malleability, high thermal and electrical conductivity, and remarkable resistance to corrosion, it is not surprising therefore that they have contributed to a considerable extent in the rapid development of aerial transport. During recent years, however, all the transport industries have been making greater use of aluminium alloys, and up to the outbreak of war it can be confidently stated that the major consumption was absorbed in the construction of road and rail transport vehicles, aircraft and marine vessels.

These industries absorbed a steady heavy tonnage of aluminium and aluminium alloys in various forms ; sheet and sections for body-work, sand- and gravity die-castings for parts of the engines, and pressure die-castings for various fittings. In the field of aerial transport, the use of aluminium has become obligatory, and in some respects this position was being approached in the motor-car industry, while in heavy transport vehicles the use of aluminium pistons, crankcases, gearcases, radiators, etc., has become general, while aluminium cylinder heads are increasingly used. Since the outbreak of hostilities the aluminium industry in this country has been controlled and the output directed primarily to meet the demands caused by huge Air Ministry requirements.

As in the war of 1914-18, which marked the beginning of widespread interest in aluminium, when much important research work was begun, so the present war may bring to light developments of a striking character, but of greater value at the moment is the fact that recent years have witnessed great strides in improving existing alloys and methods of working and fabrication. By improving technique, results achieved in normal practice compare very favourably with those obtained in the laboratory, but with increasing activity in certain branches of industry there is need for technical information which will help to a better understanding of the problems presented, and in doing so facilitate the application principles and practices which give satisfactory results.

It is in an effort to meet this need that METALLURGIA has devoted a Supplement to practical aspects of production. The initial idea was to present a complete review of manufacturing processes ; this proved, however, to be too ambitious and comprehensive, and it was necessary to compromise, concentrating upon those sections which may be regarded as of greater importance or of wider interest, and it is believed that much valuable information is presented.

Progress in aircraft construction and in aeronautical engineering have been phenomenal. There has been a growing need for high-grade light alloy structures and for high-strength alloy sheet. The demand for alloy sheet is so great that very few firms are now rolling aluminium sheet, production is almost entirely concentrated on alloy sheet. Some of these alloys are simply work-hardened by cold rolling, and are slit to size immediately after cold rolling. The heat-treatable alloys require to be heat-treated after cold rolling, so that sheets can be marketed in the heat-treated condition.

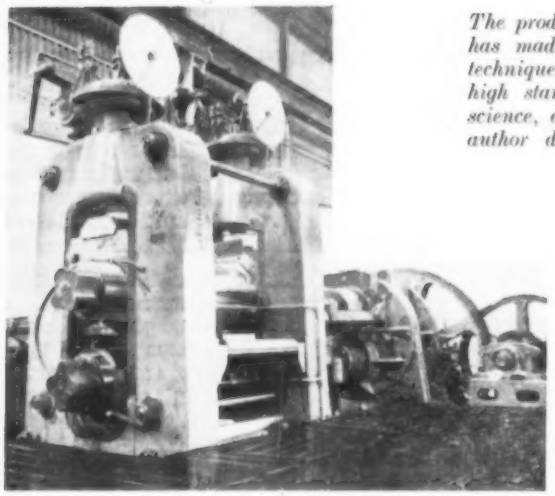
Progress has been phenomenal, and what of the future ? Who would venture to predict to what additional uses aluminium will be put even in the next few years ? It is still, in the practical field, a new metal : before the end of the present war, as the result of research going on in this country, America and the Continent, aluminium may be used for purposes that are yet the domain of ferrous alloys.

R. W. B.

Aluminium and Aluminium-Alloy Sheet

By William Ashcroft

The production and use of aluminium and aluminium sheet has made great progress in the last twenty years. The technique developed on the production side has reached a high standard, mainly as a result of the application of science, engineering and metallurgy, and in this article the author deals briefly with the main practical aspects of production.



Courtesy of W. H. A. Robertson & Co. Ltd.

Fig. 2.—A two-high non-reversible hot breaking down mill for aluminium slabs.

ALUMINIUM and aluminium-sheet production is sometimes thought to be a simple process by comparison with the rolling into sheet of other ferrous and non-ferrous metals and alloys. It is not proposed to attempt to make comparisons here, because the rolling of all metals and alloys present their own particular problems which must be solved to obtain reasonable control over the operations involved, but the technique developed to produce aluminium and aluminium-alloy sheet, of the high standard now available, is the result of the application of modern science, engineering and metallurgy. In a comparatively short article, such as this, it will not be possible to deal with this technique in detail, but an effort will be made to deal briefly with the main aspects of production.

Both commercially pure aluminium and various aluminium alloys are rolled into sheet. The former is graded according to its impurities. For normal purposes a minimum of 99% aluminium is regarded as the ordinary grade; the chief impurities are silicon and iron, the percentages depending upon the source and grade of the metal. A wide range of aluminium alloys is rolled; it comprises two main classes—the non-heat-treatable alloys and those that obtain their high mechanical properties by heat-treatment. In addition to the main types of sheet mentioned, composite sheet is rolled in which the base metal comprises a strong aluminium alloy, over the surface of which is a thin covering of aluminium. In this instance, advantage is taken of the corrosion-resistance property of comparatively pure aluminium to protect a strong alloy which is not so resistant to corrosion.

Usually, aluminium sheet is produced to meet definite specifications with regard to chemical composition of the metal and the mechanical properties of the sheet, though many consumers are more concerned with the behaviour of the sheet in drawing, spinning, stamping, bending and other forming operations. The ordinary commercial grade containing 99+% aluminium (having impurities normal) is satisfactory for many purposes. For some purposes, however, sheet of greater purity is required, especially when it is to be used for the construction of chemical apparatus. In such cases the minimum aluminium content may be 99·5 to 99·75%, and for exceptional purposes greater purity sheet is available.

Aluminium alloys are rolled into sheet for a wide variety of purposes when a material stronger and stiffer than ordinary aluminium is required. When the parts to be manufactured are not highly stressed, sheet from non-heat-treatable alloys is used; but when they are to be highly stressed, alloy sheet is used, the properties of which are greatly improved by heat-treatment. Non-heat-treatable sheet is marketed at a little higher price than ordinary commercial aluminium sheet, and both are less expensive than heat-treatable alloy sheet. Much experimental and research work has been done with a view to securing better alloys in the heat-treatable range, and while a considerable list of alloys of this character has been developed, the bulk of present industrial requirements are readily met from a few types of aluminium alloys containing copper-silicon-magnesium, silicon-magnesium, and copper-magnesium-nickel, the latter containing small percentages of iron, silicon and titanium.

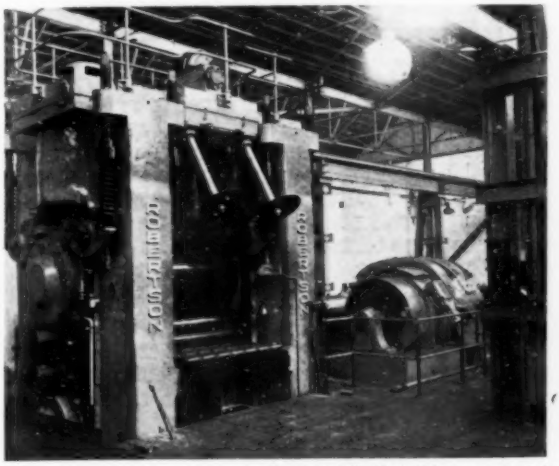
Because of the wide range of operations for which it is employed, commercial quality aluminium sheet is marketed in five tempers. Thus, between the extremes of soft and hard, there are three additional tempers of varying degrees of hardness, which give a range of mechanical properties and enable a selection to be made to meet the requirements of a particular application. The temper is governed by the amount of work hardening produced during the rolling operations. The medium-strength alloys are also available in the form of sheet in several tempers. They have greater strength than commercial aluminium in the corresponding temper, and some are practically as ductile and offer just the combination of properties required for forming without the complication and expense of heat-treatment. The heat-treatment alloy sheet is used for more high-stressed parts, but usually must be worked in the annealed condition, and the special properties obtained by subsequent treatment.

In addition to various tempers, aluminium and aluminium-alloy sheet is produced in many grades, sizes, gauges and surface finishes to meet the diverse requirements of

Fig. 1.—A hearth-type electric furnace with a hearth capacity of 2 tons and an output of 6 cwt. per hour.

Courtesy of Electric Resistance Furnace Co. Ltd.

consumers. Aluminium and its alloys are rolled in flat sheet and strip sheet, the former in a variety of sizes, usually the larger sizes; strip sheet, on the other hand, is rolled in long lengths and coiled. Usually the finishes produced are bright or grey, but for special purposes sheet may be supplied with an extra-bright finish.



Courtesy of W. H. A. Robertson & Co. Ltd.

Fig. 3.—A four-high sheet rolling mill of powerful design The mill shown is fitted with rolls of 60-in. face, but heavier mills of this type are also installed with rolls up to 84-in. face.

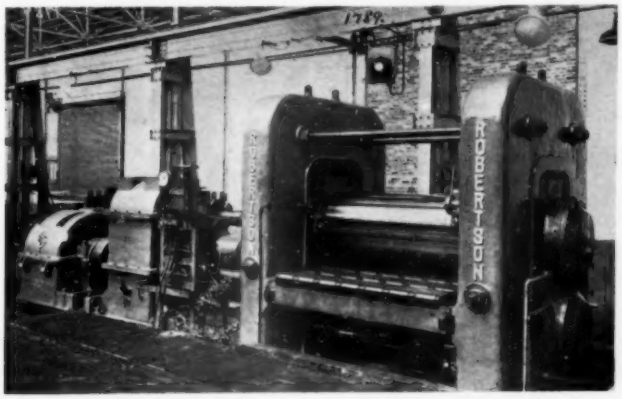
In normal practice any gauge and size of sheet can be produced within the limits of the rolling ingot or slab, the rolling mill equipment, and the tonnage involved, but standard sizes and gauges are marketed by the producing firms. In British practice aluminium and aluminium-alloy sheet is rolled to thicknesses corresponding to Standard Imperial Wire Gauge classification. Coiled sheet, in aluminium, is not usually made thicker than 12-gauge, whereas aluminium-alloy coiled sheet generally does not exceed 14-gauge. The thinnest sheet, unless for special purposes, is that of 30-gauge. It should be remembered that with the production of thin sheet there is increasing difficulty in obtaining the range of tempers by cold rolling, because after annealing it is necessary to reduce the sheet by a certain minimum amount of thickness on the first pass through the rolls to make good material.

The success achieved in the production of aluminium and aluminium sheet is dependent upon every operation in the process, not the least of these being the quality of the rolling ingot; their production involves many mechanical difficulties and also a number of complex metallurgical problems. Much attention has been given to these factors and a great amount of research and experimental work has been done to raise the standard of aluminium sheet production in this country to its present high level. It is only possible to refer briefly to some of these factors.

Many mills receive supplies of rolling ingots or slabs from another section of the same concern, and the two works may be widely separated; on the other hand, independent mills may obtain supplies from manufacturers, or they may be equipped to make their own. In any case, good rolling ingots require care in the selection of raw material from which they are made, as well as in the adoption of modern technique in the melting and pouring of the metal.

Melting Practice

Usually the melting charges are made up by compounding proper proportions of pig and scrap metal, so as to yield the required composition of metal for rolling. This applies to aluminium and the various alloys. For high-quality sheet metal the furnace charge may comprise pig metal only—the composition corresponding to that required in the sheet,—but for the usual run of rolling ingots a variable quantity of scrap is added to the furnace charge. Mill scrap and sheet cuttings of known composition can be charged direct with pig metal, but scrap of doubtful composition, or which has not been kept clean, should be remelted, refined, pigged and analysed before using it in the production of rolling ingots. Greater care is now



Courtesy of W. H. A. Robertson & Co. Ltd.

Fig. 4.—An improved new type of two-high planishing mill for sheet with a roll face of 60 in.

exercised in the marketing of secondary metal, and its use has economic advantages. Generally, the proportion of scrap or secondary metal to primary metal is higher for rolling alloys than for rolling commercially pure aluminium, but the composition must be known so that the requisite amount of alloying metals can be added to produce the desired composition. When metals of relatively high-melting points, such as copper, manganese, silicon and nickel are to be added to aluminium, it is advisable to use an intermediate alloy as a vehicle. The use of these alloys, known as hardeners, which contain a high percentage of the element desired in the rolling ingot, are generally necessary to ensure good results.

Apart from soundness and good structure, the quality of rolling ingots is determined by their composition, freedom from dissolved gases and foreign included matter, whether the metal from which they are made is primary, secondary or scrap metal. Ingots must be free from shrinkage cavities, cracks and foreign metallic inclusions. Smooth surfaces are desirable; any discontinuities in aluminium ingots will not weld on hot rolling, as in the case of some kinds of steel, but will persist throughout all rolling operations.

The crystal structure of the ingots has a considerable influence on the quality of the rolled product. It is generally considered that the most suitable structure is one consisting almost entirely of small equiaxed crystals, the presence of columnar crystals being undesirable. The columnar and equiaxed crystals behave differently during the formation of the rolling texture. Planes of weakness formed by columnar crystallisation may give rise to cracking and lamination in rolling. The speed of solidification in the ingot mould has a direct bearing on the crystal structure, but careful adjustment is necessary to eliminate as much as possible the direct segregation resulting from slow cooling and the inverse segregation resulting from too rapid cooling.

As with most metals and alloys the melting practice for aluminium and its alloys must have regard for soundness in the rolling ingots. Many types of furnaces are used—pit furnaces, stationary and tilting crucible furnaces, stationary and tilting iron pot furnaces, open-flame rotary and tilting furnaces of several designs, stationary and tilting hearth furnaces of the reverberatory type, and electric furnaces of several designs. The choice of furnace to be employed in aluminium melting for rolling ingots depends on many factors which need not be discussed here, but the furnace capacity should be adjusted to the quantity

Courtesy of The Incandescent Heat Co. Ltd.

Fig. 5.—A battery of four recirculated atmosphere-gas-fired annealing furnaces for aluminium alloy sheets. Each furnace will treat about 3 tons of sheets per 8-hour shift.

to be melted so that the units will be as large as possible. The operation of a battery of small units is uneconomical in comparison with a large unit of equivalent capacity. Among recent furnace installations for melting aluminium is an electric furnace installed in a works producing pure aluminium sheet is of interest. This furnace, shown in Fig. 1, gives an output of 6 cwt. per hour, and has a bath capacity of about 2 tons. It is capable of producing from thin scrap ingot metal suitable for rolling. The furnace is of the hearth type, where the metal is melted on a sloping hearth before running into the liquid bath. Although this type of furnace is used fairly extensively in Germany, it is believed to be the only one of its size electrically heated in commission in this country. It is rated at 240 kw.

The details of melting practice vary with the type of furnace, and whether solid or gaseous fuels or electricity are used; but keeping in mind the need for soundness of the rolling ingots, two factors of outstanding importance must be noted—overheating must be avoided and scrupulous cleanliness must be observed. Overheating tends to cause the contamination of melts with suspended aluminium oxide; blistering of sheet, on annealing, is also a result of overheating the molten metal. On the question of cleanliness, it should be appreciated that whatever dirt or other solid foreign matter is charged into the furnace will be found in the liquid metal, and will pass into the ingot unless removed by a refining process.

When proper care has been exercised in charging the furnace and in melting the metal, fluxing may be unnecessary, but some fluxing with metallic salts may be the usual practice to refine the charge, or the molten metal may be treated with either an inert or an active gas. The methods of refining the metal vary in different works, but the temperature of the metal must be controlled. This should not exceed 750° C., the preferred temperature being between 720° and 740° C., and any tendency towards a higher temperature should be checked by the addition of cold pig, as gas absorption is more rapid with increasing temperature.

Ingot Moulds

Rolling ingots vary much in size and shape, the former being governed by the size of sheet to be rolled and the capacity of the mill; with regard to the shape, the square-edged and round-edged ingots are more common. They are cast in special chill moulds, a conventional type being the tilting vertical mould. With this type the long axis of the ingot is in a vertical position when pouring is completed, the mould being tilted from an approximately horizontal to a vertical position as pouring proceeds, and the halves of the mould moved apart by a hinged joint to release the ingot. Many types of moulds are in use, some of which are designed for water cooling. The Durville process of pouring, originally developed for aluminium-bronze ingots, is one of many methods applied to the pouring of aluminium rolling ingots. In principle, this method reduces agitation of the metal during the pouring operation by keeping the upper surface horizontal.

Ordinarily the moulds are made of grey-cast iron, but nickel and nickel-chromium cast irons have given good results. The mould surfaces should be without blemish, and are sometimes machined and polished. The application of a surface wash is not essential, but it is a common practice to whitewash the surface or to apply a graphite wash. The object is to protect the surface of the mould and to facilitate the escape of air and gases during pouring. Normally, the moulds are hot at the time of pouring, because moulds used at room temperature have a tendency to produce surface cracks, or the ingots tend to crack in the hot-rolling operations. To reduce piping, liquid metal is fed into the ingot after it is cast, maintaining, as far as possible, a level surface.

Hot Rolling

In some instances aluminium ingots are rolled direct from their moulds, when they have cooled to the required rolling temperature; in such cases the ingots are removed to a soaking furnace, where they remain at the rolling temperature until they are uniformly heated. In normal practice the ingots are reheated in a furnace conveniently located with respect to the hot mill, because it is generally considered that better quality alloy sheet is obtained with reheated ingots. The high-duty alloys, in particular, must be reheated and maintained at a suitable soaking temperature for long periods before commencing the breakdown operation, the object being to effect favourable alteration of the metal structure. When the ingots are cast, considerable care is taken in their preparation for the hot-rolling operation, particularly the heat-treatable alloy ingots, from which the surfaces of the largest faces may be machined to ensure that no scratches or tool-marks are present.

Ingots of aluminium and its alloys are broken down at a temperature of about 450° C., the actual temperature varying somewhat with the composition. Pure aluminium may be, and frequently is, hot-rolled at a higher temperature; but in reheating aluminium, and those alloys which do not need soaking to change the structure, the ingots are uniformly heated about 10° to 15° C. above this temperature to allow for loss of heat in transporting from the furnace to the mill. For many of the heat-treatable alloys a favourable change in the structure is obtained by soaking at a higher temperature; in practice this temperature generally corresponds with the quenching temperature used in the heat-treatment of the particular alloy. When these ingots have soaked for the required length of time, varying with their size and composition, they are cooled to about 450° C. before rolling, because at temperatures of about 510° to 520° C. they are not short and liable to fracture in the hot mill.

The hot rolling of aluminium and aluminium-alloy ingots is a breaking down operation which has for its object the removal of the cast structure and the production of slabs suitable for cold-rolling. An aluminium ingot is hot-rolled with a varying number of passes to obtain the required width of slab. Practice varies in different mills, but invariably, after being rolled in one direction, further passes are made with the ingot moved through an angle of 90°. The total number of passes vary, and may be about five to nine. Aluminium-alloy ingots, being harder, must not be deformed at the same rate, and a greater number of passes is necessary for similar-sized ingots. Some hard alloys, for instance, can be reduced only about $\frac{1}{4}$ in. per pass at the hot mill compared with upwards of 1 in. for aluminium.

In hot-mill practice provision must be made for lubricating the surfaces of the ingots and for cooling the rolls. Methods employed vary considerably. Lubricating the ingot improves the performance of the hot mill; it prevents

the slabs sticking to the rolls, increases the tendency of the rolls to take the material, and prevents the slabs from curling. Roll cooling contributes to continuity of operation, it reduces the consumption of lubricant and increases the life of rolls. This problem is not yet adequately solved, but many mills find that by spraying the roll surfaces with a water emulsion of a soluble oil satisfactory results are obtained. The water acts as a coolant and provides a vehicle for conveying the lubricating oil.

Hot-rolling mills for aluminium and aluminium alloys include two-high, non-reversible mills, two-high reversible mills, double-duo mills, and three-high mills. They are built in various sizes to suit the range in sizes of blanks or slabs. Mills of the two-high, non-reversible type are used considerably for hot rolling aluminium ingots ; they are similar to those used for roughing and finishing aluminium sheet, but when used for hot-rolling they are usually equipped with power-operated screw-downs. Rather large rolls are employed. Such a mill is shown in Fig. 2, equipped with an electrically operated lifting table to return the slabs to the feeding side after each pass. Aluminium ingots up to about 200 lb., and a thickness up to 6 in., can be reduced to the required slab thickness in about eight passes at rolling speeds of 200 to 250 per minute.

In general design the two-high reversible type mill is similar to the former type up to the drive, though usually heavier and stronger. This type obviates the necessity of returning the slab over the upper roll as in the case of the non-reversible type. The double-duo is favoured in a few instances ; this type comprises two pairs of rolls built into one stand. Many plants use three-high mills ; in these the ingot is partly broken down between the bottom and middle rolls, and the return pass is made between the middle and top rolls. Lifting tables operated at each side of the mill receive or feed the slab according to the direction of passing.

The thickness of blank or slab specified is normally between 0·2 in. and 0·5 in., and to ensure good working in the cold mill it is advisable to maintain a reasonable degree of uniformity in the thickness for a particular size and gauge of sheet. In practice the slab thickness is varied according to the sheet to be rolled, the final gauge being the determining factor ; other factors to be considered are the width of sheet, the temper, details of the cold-rolling, and intermediate anneals. As an indication of the influence of the finished gauge on the initial slab thickness, it is generally considered advisable in aluminium-sheet practice that the cold-reduction thickness, prior to final anneal, should be held within narrow limits. Control of cold reduction is especially important in the production of deep drawing sheet when the percentage should correspond to the initial stress for maximum grain size on annealing.

Production of Slabs

The production of slabs for rolling into sheet involves considerable work following the hot-rolling operations, since they require to be sheared and squared into suitable sizes. Scrap must be kept as low as possible for economical reasons, so that careful attention must be given to the slab size as produced by the hot mill in order that the amount of shearing and trimming to produce slabs for cold rolling will be within reasonable limits. Usually, larger allowances for this purpose are made with the hard aluminium alloys than for ordinary commercial aluminium. When flat sheet is to be produced the length and width of the slab is trimmed to the required size, and, obviously, this size will vary according to the size of sheet to be produced. When the sheet is to be coiled in the form of strip, the slab is edged to width only.

Again, with flat-sheet production, the initial ingot may be slabbed for the production of only one or several. The number necessarily depends upon the size of the finished sheets in relation to the size of the ingot. The slabs are first rough-rolled in order to reduce the thickness of the hot-mill slab as rapidly as possible, and to prepare the stock for final passes when the desired gauge and surface finish is obtained. Roughing is just as important in processing aluminium sheet products as the finishing operation, because material which is not properly rough-rolled will not make good sheet. It is the preliminary rolling operation following an anneal.

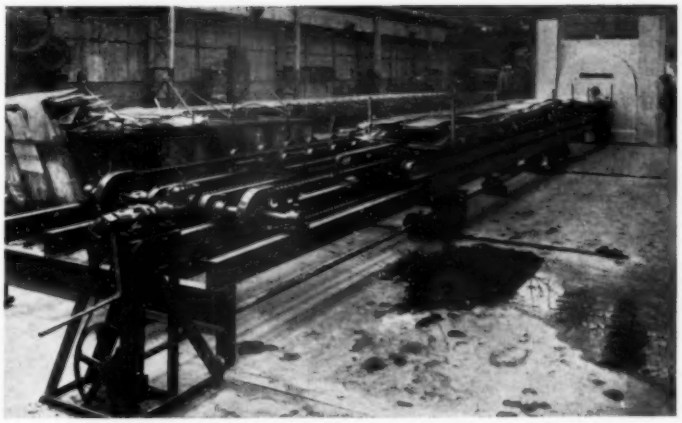


Fig. 6.—G.W.B. tubular sheet anneal furnace, with high velocity forced air circulation.

Cold Rolling

Aluminium, because of its softness and ductility, can be cold-rolled with heavy drafts, and can be substantially reduced without intermediate annealings ; the hard alloys, on the other hand, are not so easily worked, and frequent annealings are usually necessary between passes before they are rolled to the final gauge. The easy workability of aluminium, therefore, is a great advantage in the hot-rolling and subsequent roughing operations, but it creates many difficulties in finishing to gauge. Its softness causes the sheet to be easily marked by the rolls ; ripple marks, waves and buckles are readily formed ; the metal is easily scratched or the surface otherwise marred ; and its colour readily shows small flaws, particularly when it is given a bright finish which brings out small defects in sharp relief. Generally, these difficulties are increased as the gauge thickness is reduced.

The finish-rolling operations of flat sheet and coil sheet differ somewhat. Two-high mills are frequently used for aluminium sheet, but for high-strength alloys the four-high mill has several advantages, notably a reduction in the number of passes and less-frequent annealing, and a recently installed mill of this type is shown in Fig. 3. This mill has rolls 14 in. and 37 in. in diameter with 60-in. face, and is capable of exerting a rolling pressure of 1,200 tons. It is noteworthy that the supporting rolls are carried in " Flood " lubrication bearings. Mills for coil sheet are of similar type to those used for flat sheet, but they are equipped with coilers. Normally, flat sheet is produced in a large number of passes, whereas with strip sheet the number of passes is very much reduced ; the number of passes will, of course, depend upon the amount of finishing allowance on the rough-rolled sheet and whether the finished sheet is of medium or light gauge.

It is impossible to give any fixed rule regarding the number of passes, although, in practice, the finishing allowance should be the minimum for the particular type of sheet, but, for flat sheet in particular, the number should be so arranged that the final pass produces a flat sheet. In rolling heavy gauge flat sheet even one pass too many may cause the sheet to buckle. The finish rolling of flat sheet is so much of an art that it is difficult to give information which is applicable to every class of aluminium and aluminium sheet, but, generally, more passes are required to finish sheets in a softer temper than in a harder temper, since the drafts must be less. It can be stated,

however, that the number of passes depend upon the condition of the rough-rolled material, its thickness with regard to the finished gauge, the thickness of the finished sheet, the size of the sheet and its degree of flatness desired, the temper and the kind of surface finish required.

A bright surface finish on aluminium sheet is obtained by rolling in contact with highly polished rolls. Cast-iron rolls pick up a coating rather quickly when aluminium is passed, whereas forged alloy steel rolls are not coated so readily. Neither type of roll is affected to the same extent when rolling aluminium alloys, but, generally, the harder the alloy the less the tendency for rolls to be coated. For the finishing passes in particular the rolls must be cleaned and retain their polish. The degree of polish depends on many factors concerned with the treatment of the material from the ingot stage, but the rolls or sheet may be swabbed with a thin mineral oil, such as paraffin oil, which not only prevents the sheet sticking to the rolls but improves the surface polish. In Fig. 4 is shown an improved new type of two-high planishing mill for aluminium and aluminium alloy sheet. The roll face is 60 in., and the mill is fitted with hydraulic roll adjustment, which is under exact control of the operator, so that the rolling pressure can be varied and adjusted to the finest limits quickly.

A grey semi-matte finish is imparted to sheet surfaces when the sheet is passed on mills having coated rolls. The coating mainly consists of aluminium oxide, which is picked up by the rolls, and because cast-iron rolls take this coating readily mills for grey sheet are usually equipped with chilled-iron rolls. Care must be taken to ensure that the coating is continuous, that it does not build up too heavily, and that it is kept clean. A light mineral oil may be used as a lubricant, but it should be used sparingly.

As has already been pointed out, frequent annealings are necessary before the hard alloy sheets receive their final pass, and many types of furnace equipment are designed for this purpose. In Fig. 5, for instance, is shown a battery of recirculated atmosphere-gas-fired annealing furnaces for alloy sheet. Each furnace has a heating chamber 17 ft. long, 5 ft. wide, and 3 ft. high. The working temperature is 400° C., and each furnace will treat 3 tons of sheets per 8-hour shift. The whole battery is served by a two-fork charging machine of the cantilever type.

A new type of annealing furnace for alloy sheets is shown in Fig. 6. It is electrically heated, and incorporates a new development in possessing high-speed air circulation. A multiblade centrifugal fan gives air speeds up to 30 ft. per second with extremely good temperature uniformity. As will be seen, this furnace is also fitted with a special charging machine.

Scrupulous cleanliness must be observed in the finish-rolling operations. No foreign matter should fall on the rolls, sheet or tables, otherwise the finish will be marred. Scratching surfaces when handling the sheets must be guarded against.

Working Aluminium Tubes and Sections

By Norman L. Brown

IN working aluminium or aluminium tubes and sections great care must be taken to preserve the surface. Scratches must be guarded against, so that positions for bending, or other work intended, should not be scribed on the surface with sharp-pointed instruments but by means of lead or a coloured pencil, otherwise the notch sensitivity of the material may result in cracks or fractures when forming the components. Preferably, the tools used should be preserved for working aluminium, otherwise they must be carefully cleaned to remove all traces of heavy metals. All tools should be as smooth as possible and perfectly clean at the time of use.

The capacity of aluminium, or its alloys, to be worked without cracking depends upon the ductility of the material. Tubes or sections in soft aluminium are readily bent or swaged cold, but with increasing hardness in temper these operations become less easy to accomplish, and heat may be required to anneal the metal to facilitate bending or swaging. The application of cold work upon the soft metal causes the aluminium to harden, but the soft condition is restored by annealing, so that in order to accomplish the required amount of bending or swaging without fracture it may be necessary to carry out the operations in easy stages with several intermediate anneals. Normally, annealing is readily effected by heating the particular part with a blow-lamp to a temperature of about 350° C. The heating should be as regular as possible about the part to be worked. Unfortunately, it is not easy to determine the temperature of aluminium when on work of this kind, but a good indication is obtained by rubbing the point of a sharpened piece of wood over the heated surface, when the temperature is at about 350° C. a light-brown mark is just visible.

In tube working the amount of deformation may be such as to warrant hot-working, in which case the temperature of the metal should be kept in the neighbourhood of 400° C. At this temperature an unlimited amount of work can be carried out without work-hardening taking place. The choice between hot- and cold-bending of tubes and sections, obviously, must depend on the radius of the curve in its relation to the diameter of the tube or the width of section in the direction of the bend. Other factors involved concern the temper or hardness of the metal. The effect of hot-working must also be considered, since it destroys the hardening obtained by cold-work. This applies to the non-heat-treatable alloys of the aluminium-manganese, aluminium-magnesium-manganese, and aluminium-magnesium types as well as of pure aluminium. In the case of the heat-treatable of the type aluminium-magnesium-silicon, aluminium-copper and aluminium-copper-magnesium, heat-treatment operations will restore the original condition when the size permits.

Whether hot- or cold-working is adopted may also depend upon a subsequent surface treatment which may be applied to the components. Anodic or chemical oxidation processes give satisfactory results only when the parts treated are in a uniform condition, a condition which with non-heat-treatable alloys is only achieved by annealing the parts.

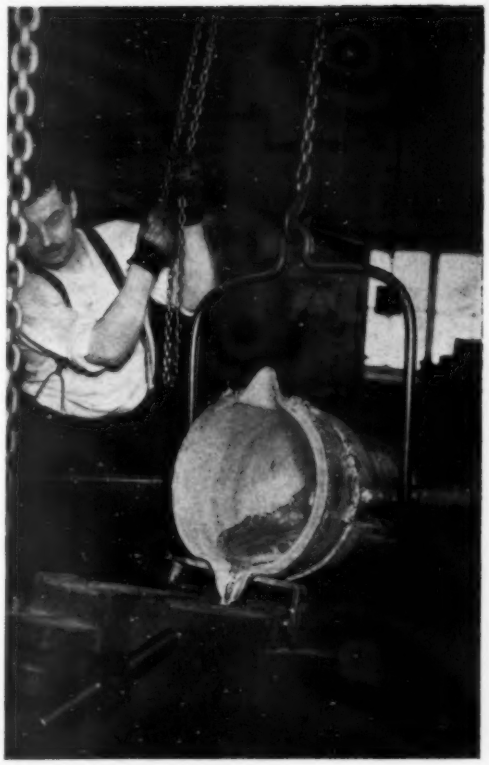
Special roll-bending machines are available for tubes of any diameter and wall thickness which are especially suitable for production work, but simpler devices which can be adjusted to particular requirements are useful for constructional work. Small tubes, for instance, not exceeding ¾ in. in diameter can be bent on a half-round grooved jig without special precautions, but larger tubes must be filled with material which will not change its volume. Clean, dried quartz sand is especially suitable for this purpose, whether the hot or cold method of bending is adopted. The tube must be completely filled and the ends plugged. Some tubes which are to be subjected to cold-bending are more conveniently filled with a low-melting-point metal, like Wood's metal, which is removed by heating to a temperature of less than 100° C. when the forming is completed.

The bending of sections is frequently more difficult, especially when the direction of bending coincides with the plane of a web, when there is a tendency to distortion. Generally, the work is not so accurate, when completed, as is possible with tube when hot or cold methods are adopted, but distortion can be considerably reduced by filling the section as much as possible with sheet-metal strips. This applies more particularly to complicated and large sections, since many small sections do not need any special treatment.

The Production and Treatment of Aluminium Alloy Castings

By A Special Contributor

The production of castings free from defects has been one of the most important problems of the industry, particularly those castings which are subsequently heat-treated. Rigid specifications are now inseparable from the work of the foundry in the light alloy field, and in this article the main factors involved in the production of aluminium alloy castings are discussed.



Casting from a 200-lb. crucible in a typical aluminium foundry.

ALUMINIUM alloy castings are produced by the sand, gravity or pressure die casting processes. Sand casting is normally employed for the larger types of castings, and is responsible for by far the greater bulk of aluminium alloy castings ; it is the process employed when only a moderate number of castings of similar shape and size is required. Where large quantities of similar castings are involved it may be more economical to adopt either the gravity or pressure die-casting process. The choice between these two methods depends, to a large extent, on the number required, as the dies for producing castings by the pressure process are costly. Compared with sand casting, either of the die-casting methods gives greater accuracy of production, a better surface finish, and enable thinner sections to be successfully cast.

The production of uniformly sound castings is largely dependent upon the melting procedure adopted. Very careful control is necessary, the temperature of the molten metal, for instance, should not be raised unnecessarily above 750° C. Apart from the fact that high melting temperatures cause excessive oxidation and gas absorption, and adversely affect fuel consumption, when the melting temperature exceeds 770° C. an increase in the grain size of the castings will generally result. In addition to control of temperature, the importance of cleanliness in the melting operations cannot be over-estimated.

Melting

Furnaces for melting aluminium alloys fall into two main classes—direct flame furnaces, in which the heating medium comes into direct contact with the metal, and indirect flame furnaces, in which the heat is transmitted through an intermediary. Open-hearth and barrel type furnaces come under the heading of direct flame furnaces. Of these, the open-hearth type is especially suitable for alloying large quantities of metal ; generally, however, the indirect flame furnaces are in more common use. These are in the form of containers which tilt and which provide an economical type that has largely displaced the lift-out crucible type of furnace with a plumbago crucible, though the latter has some advantages in the casting of aluminium silicon alloys. Cast-iron pots have advantages over refractory clays as a material for crucibles, notably in better thermal conductivity, superior strength, lower cost, and greater facility of production. Precautions must be constantly observed with iron melting vessels, however, if contamination of the aluminium alloy with iron is to be avoided. A wash consisting of whitening, 5 lb., water, 2½ gals., and sodium silicate, 3 oz., applied by brush to the inside of the cast-iron pots and dried, will be found to be effective for crucibles which are completely emptied after each melt.

Fuel is usually gas or oil, both of which are reasonably economical and convenient. So far, electric furnaces have been used but little for aluminium melting in the foundry, but increasing interest has been taken in these furnaces in recent years, particularly low-frequency induction furnaces, which offer great possibilities, especially in connection with the production of die-castings for holding the metal at a definite temperature. Many different types of furnaces are in use for melting aluminium in foundry practice, but a detailed discussion on their relative merits is unnecessary here.

At all times the melting equipment should be properly maintained and cleaned. The necessity for this cannot be stressed too greatly. Great care must be taken to avoid contamination by dross. Where a variety of metals are used, they should be systematically segregated. The greatest difficulty, however, is due to the absorption of gas. The ability of aluminium alloys to absorb gases increases rapidly with temperature and with the time metal is held at elevated temperatures. Such gas absorptions may cause serious porosity ; it is important therefore that the temperature of melting should be as low as possible, and unless a neutral atmosphere can be maintained, the holding time should also be as short as possible. Aluminium alloys within the safe temperature range do not change colour in the molten condition ; efficient pyrometric equipment is therefore advisable. Closed or beaded-end thermocouples protected by a coated cast-iron tube, are recommended. The coating may be the same as that given for the cast-iron melting pot. Agitation of the metal in the furnace should also be avoided as much as possible, since oxides formed in this way are only partly removed by skimming and are often trapped in the casting.

Fluxing is not usually necessary, but it is useful in minimising dross losses, and is particularly beneficial when considerable foundry scrap is included in the charge. In such cases, active or inert gases, volatile fluorides and chlorides, or stable metallic salts may be used. Of these, aluminium chloride or a mixture of chlorides and fluorides, or cryolite, are most commonly employed, or one of the proprietary fluxes may be used. In using solid fluxes, it is necessary to make sure that they are absolutely dry ; that they are introduced into the metal in a way that avoids excessive agitation, and that they are used in such a way that as much metal as possible is subjected to their action.

Using a hand shank for casting small work on the floor. This method enables the temperature of the metal to be kept low.

Gaseous fluxes should be led into the bottom of the melt and allowed to bubble up through the metal. The introduction of grain-refining agents with the flux has received some attention in recent years, and such elements as titanium and boron may be added in this way.

If the alloy to be cast is made up in the foundry, the aluminium is first melted and at approximately 700° to 750° C. the necessary alloying elements are added, usually in the form of key or master alloys containing aluminium and a known high percentage of the alloying element. The order of adding these elements is generally as follows: Copper, silicon, iron, manganese, nickel, magnesium.

Sand Casting

In general, the methods for making sand moulds for the casting of aluminium alloys are those which serve for other metals. Methods of handling and conditioning of sand, of core-making and moulding, are not substantially different whatever metal is used, but the properties of aluminium alloys—in particular their low specific gravity and their tendency to hot shortness—made it desirable that certain foundry practices should be observed if the best results are to be obtained.

Sand must be selected with some care, as the aluminium has great mobility and sand-searching characteristics. For green sand moulds a finer grained, naturally bonded sand than would be used for iron castings is preferable—such a sand, properly treated, gives a good surface to the castings, and since the volume of gas generated at the time of casting is much less than with cast iron, it will be sufficiently open to allow the escape of mould gases. The sand should be worked as dry as is consistent with maintaining the shape of the mould. For most dry sand cores, a silica sand with a fineness of from 70 to 90 will be found adequate when bonded with one of the many artificial bonds. The surface produced on the casting may be improved by the use of a talc or graphite core wash. Control of the sand must be exercised with care, as aluminium alloys tend to be hot-short. Moulds should be lightly and uniformly rammed, and both mould and cores should be soft enough to be easily crushed by the casting as the metal solidifies and contracts.

In pouring aluminium alloys, it is important to use the lowest pouring temperature possible consistent with the successful filling of the mould. This temperature is largely governed by the thinnest section of a casting, and the location of this section with respect to the gates through which the molten metal enters. Porosity of castings increases with both pouring temperature and thickness, and not only impairs the qualities of strength and appearance, but has a damaging effect upon the mechanical properties. Pouring temperature for average castings should be between 650° and 720° C., according to the size of section, intricacy, and surface area of the casting. The pouring height should be kept as low as possible in order to minimise turbulence, and during the pouring the stream of metal should be kept unbroken. In this way exposure to steam and air will be reduced, and there will be less danger from trapped and absorbed gases.

The strength properties of aluminium alloy castings can be greatly affected by the location and types of the gates used. It has been established that the use of suitable gates can increase the strength of castings by as much as 50%. In general, multiple gating is recommended, as it allows of a lower pouring temperature and a uniform but rapid rate of solidification in all parts of the casting. The gates should be arranged in such a manner as to promote progressive feeding—that is, the sections remote from the gate should be first to solidify. If light sections are adjacent to heavy sections the gates should normally be placed on the lighter sections. Gates should be so placed that the metal enters the mould with as little agitation as possible, preferably at the bottom. For alloys that oxidise quickly the use of skim gates is often advisable.

It is generally desirable to use a large number of risers, placing them so as to feed the casting progressively as it solidifies. In arranging the position of risers, however, some consideration should be given to the ease of removing them in fettling. Reasonable care should be exercised to ensure that the casting is not subjected to undue strain by risers during the time of cooling. In some cases the easing of sand about risers may be necessary to enable the casting to contract without damage.

As with the production of castings in other metals, by the intelligent use of chills embedded in the mould certain sections can be strengthened without an increase of the section thickness. Similarly, where thick and thin sections solidify at unequal rates, chills will hasten the solidification of the heavier section and will reduce the possibility of cracking. The chills commonly used in moulds for aluminium sand castings are usually aluminium, copper, or cast iron, but they should be treated to reduce the possibility of sweating and consequent blowholes. Recently, refractory compositions which absorb heat almost as quickly as iron or copper have been investigated in relation to their use as chills or denseners. The material is in a plastic condition, which is readily moulded to any desired shape and subsequently dried prior to use. This material does not sweat as do metal chills.

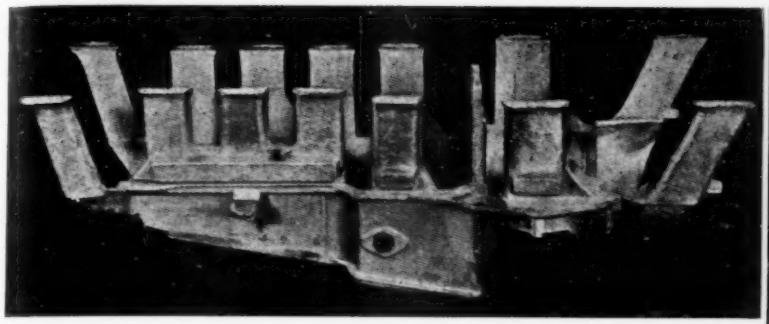
Die-casting

The two methods of die-casting—the gravity and the pressure processes—differ considerably. The gravity process, also referred to as permanent mould casting, follows to a large extent the technique of sand casting, but the moulds and, usually, the cores are of a permanent character, and are made of cast iron or steel. Pressure die-casting, by comparison, is more highly mechanical, and manual operations are reduced to a minimum, but the radical difference between the two processes is that in pressure die-casting the metal is forced into the die under high pressure.

Pressure die-castings are more accurate and can be cast in thinner sections. There are several groups of aluminium-base alloys which represent a considerable portion of the bulk of die-castings produced, of these the aluminium-silicon alloys are of particular interest in pressure die-casting. These alloys have a high fluidity, and they are sufficiently fluid just above their melting point to enable them to be pressure cast at a lower temperature than that of the other alloys. This adds to the die life, and the castings are more likely to be sound.

Gravity Process

As in sand casting, so in the gravity process of die-casting it is necessary to lay down and follow a well-conceived and clear-cut procedure if castings free from porosity, shrinks



An aluminium-alloy sump casting. Note the risers in this sand casting. They are arranged both to ensure the production of a sound casting and to facilitate ease of removal.

and cracks, are to be produced. It is important to guard against agitating the fluid metal, otherwise blowholes in the castings will result. To avoid cracking, cores must be withdrawn gently and at the right moment, and temperature and feeding must be carefully controlled. Probably the most difficult of the problems presented is that of shrinkage. Indeed, the methods of combating it—gas flames to keep the mould hot, to retard the solidification of

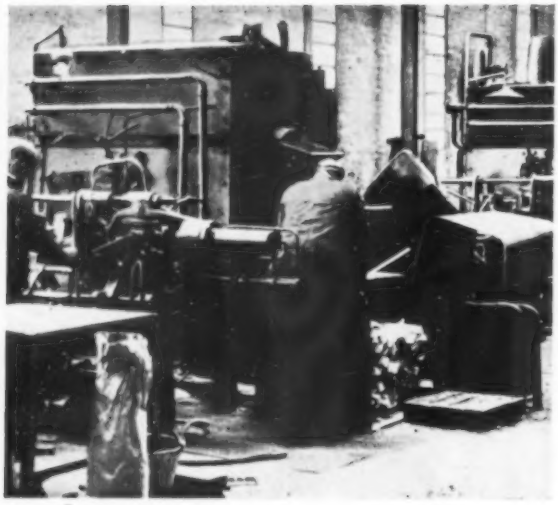
The finished aluminium alloy castings are subjected to stringent tests.

CAST ALLOYS—NOT HEAT-TREATED.

Type.	Major Constituents. (Balance Al.)						Min. Mech. Properties.						Commercial Designation.
							U.T.S. Tons/sq. in.		0·1% P.S. Tons/sq. in.		Elongation % in 2 in.		
	Cu.	Mg.	Mn.	Ni.	Zn.	Si.	Sand.	Die.	Sand.	Die.	Sand.	Die.	
Al/Cu	7·6	—	—	—	—	—	7·5	9·0	3·5	3·5	1·5	3·0	4.L.11, 232
	12·0	—	—	—	—	—	7·0	9·0	4·5	4·5	—	—	3.L.8, 260
Al/Zn/Cu	2·75	—	—	—	13·5	—	9·0	11·0	3·5	3·5	2·0	3·0	3.L.5, 465
Al/Si (med.)	—	—	—	—	—	12·0	10·5	13·0	3·5	4·5	5·0	8·0	Alpax, 160 L.33
Al/Mg/Mn	—	3·0 to 6·0	0·25 to 0·75	—	—	—	9·0	11·0	5·0	5·0	3·0	5·0	Birmabright D.T.D.165
Al/Cu/Ni/Mg	4·0	1·5	—	2·0	—	—	10·0	12·0	8·5	8·5	—	—	"Y" Alloy 218, 2.L.24

CAST ALLOYS—HEAT-TREATED.

Type.	Major Constituents. (Balance Al.)							Min. Mech. Properties.						Commercial Designation.
								U.T.S. Tons/sq. in.		0·1% P.S. Tons/sq. in.		Elongation % in 2 in.		
	Cu.	Mg.	Mn.	Ni.	Si.	Fe.	Cd.	Sand.	Die.	Sand.	Die.	Sand.	Die.	
Precipitation treated 150° to 175° C. Al/Si/Mg Plus Mn	—	Up to 0·6	Up to 0·6	—	12·0	—	—	11·0	15·0	6·0	8·5	1·5	3·0	Alpax Beta, 161 D.T.D.240
Al/Cu/Ni/Mg Plus Fe, Si, Ce	1·3	0·1	—	0·9	2·25	1·2	—	11·0	12·5	7·5	8·0	2·5	4·0	RR.50 D.T.D.133B
Solution treated 425° to 535° C. Al/Cu/Ni/Mg	4·0	1·5	—	2·0	—	—	—	14·0	18·0	13·0	14·0	—	2·0	"Y" Alloy, 218, L.35
Plus Fe, Si, Ti	2·5	0·75	—	1·5	1·2	1·2	—	14·0	20·0	11·5	13·0	—	5·0	Ceralumin D D.T.D.250
Al/Cu/Cd/Mg Plus Mn, Si, Ti	3·25	0·8	Up to 0·5	—	Up to 2·5	—	1·5	14·0	17·0	11·0	12·0	3·0	5·0	Aeral A/H D.T.D.294
Al/Mg	—	10·0	—	—	—	—	—	16·0	18·0	11·0	13·0	7·0	12·0	BA/29, NA350 D.T.D.300
Solution and precipitation treated Al/Si/Mg Plus Mn	—	—	—	as above	—	—	—	15·5	19·0	13·0	16·0	—	—	Alpax Gamma, 161, D.T.D.245
Al/Cu/Ni/Mg Plus Fe, Si, Ti	2·1	0·5	—	0·8	2·5	1·1	—	19·0	22·0	18·0	19·0	—	—	RR.53C D.T.D.389
Plus Fe, Si, Ce	2·5	0·75	—	1·5	1·2	1·2	—	18·0	23·5	17·5	20·0	—	—	Ceralumin C D.T.D.255



A typical gravity die-casting machine in operation on the production of aluminium-alloy die-castings.

the metal in certain parts, whitewashing of other parts of the mould requiring slower cooling rates, water cooling of core parts, the use of sand cores in difficult positions, chills for rapid local cooling—are still not completely satisfactory. The permanent mould should be so designed that it facilitates rapid stripping of the casting, so that contraction will not be unnecessarily obstructed.

When the annual requirements for a particular casting necessitate about 500 and less than 5,000, the merits of the gravity process is worthy of careful consideration from an economical point of view. The weights of these die-castings can be more accurately controlled than those of sand castings. Sections less than $\frac{1}{8}$ in. thick can be cast, and the section thickness can be controlled to within 0·01 in. As a rule, permissible variations in dimension are less rigid in gravity than in pressure die-casting. For products such as pistons, where soundness is important, gravity die-casting will be found to yield the best results. Castings weighing over 50 lb. each are made by this process, but the greater number of gravity die-castings do not exceed 10 lb. each.

Pressure Process

To force the metal into the die cavity and hold it there until it solidifies usually requires a hydrostatic pressure of between 100 lb. and 500 lb. per sq. in. Special alloy steels are necessary for the dies, as ordinary carbon steels tend to be corroded or dissolved by aluminium alloys. Heat-treated chrome-vanadium steels are most commonly used for the purpose. When castings are required in large quantities, it is often more economical to make dies capable of producing two or more castings at one shot. Dies are often built to make as many as 20 castings.

As the die halves open and close in one direction only, and the casting can be removed in one direction only, undercuts or projections must be provided for by a motion of a part of the die in another direction, necessitating the use of a slide or side movement. Holes or cavities must also be formed by cores sliding back and forth along the lines of the axis of these holes.

It is extremely important that the amount of gate should be kept as small as is compatible with an ability to fill the die, the opening being made of as thin a section as possible. As the metal which solidifies in the gate must be broken off afterwards, giving the surface a somewhat ragged appearance, the gate should not be placed on a surface which is later to be polished or highly finished.

The maximum dimensions for pressure die-casting are reckoned as 20 × 36 × 10 in. in size and 15 lb. to 18 lb. in weight, although if the necessary equipment were to be built it is possible that considerably larger castings could be made. As it is, pressure die-castings are usually small. Complicated castings of over 7 lb. in weight can be produced in quantities of over 100,000. Great dimensional accuracy and very close tolerances indeed are possible. For special purposes, castings have been produced in commercial quantities with limits of 0·001 in. across the parting line. Thinner sections can be obtained by pressure die-casting than by any other method. A uniform wall thickness of 0·080–0·100 in. can be quite easily obtained in castings as large as the available equipment can produce.

This process may be adopted for bulk quantities of 5,000 and upwards ; it gives fine detail, and the resulting castings are usually accurate enough to represent the finished job ; it is particularly useful when the castings require to have inserts firmly and accurately located.

Heat-treatment of Castings

A remarkable increase in the strength and elastic properties of certain aluminium alloys can be effected by heat-treatment. Unlike steel, aluminium alloys do not harden by quenching only, and a subsequent low-temperature treatment may be necessary in order to achieve the highest properties. Casting conditions, particularly the rate of solidification, affect the results obtained by subsequent heat-treatment. A coarse-grained structure is detrimental, as it slows down the rate at which the various metals or compounds go into solution during solution heat-treatment, and reduces the rate of subsequent ageing. Some caution should be exercised in exposing massive or intricate castings to the rigour of full heat-treatment, involving a sudden quench from a high temperature, as distortion or cracking may result.

Solution treatment is a high-temperature treatment, carried out either in fused sodium nitrate baths, which allow very close control of temperature, or batch-type electric furnaces with forced air circulation. Uniform heating and an immediate and uniform quench are of the greatest importance. The heating temperatures lie between 450° and 550° C., each alloy having its own specific temperature, which should be rigidly adhered to within a margin of ± 5° C. The duration of heating at the temperature, or soaking time, is equally as important, and, when determined, should be carefully observed.

The object of this solution treatment is to bring the soluble constituents of the alloys into solid solution, and by rapid cooling to retain this solid solution in a supersaturated condition. The treatment is suitable for alloys which are to combine high strength with maximum shock-resisting qualities. Some castings, in which the metal is rapidly cooled, as in the case of die-castings, do not need solution heat-treatment and quenching, hot age-hardening only being required. Because of their finer grain, chill castings respond more readily to heat-treatment than sand castings, and the time period of soaking at the quenching temperature is much shorter in the case of the former, and the mechanical properties obtainable are better. Precipitation treatment or ageing is a low-temperature treatment, being carried out usually at between 150° C. and 250° C. As some alloys attain similar degrees of hardness and strength after natural ageing for a longer period, this treatment is often referred to as "artificial ageing." As in the solution treatment of castings, in precipitation treatment each alloy should be heated to its required temperature and should be maintained at that temperature for a specified time. This treatment may be used alone, as already mentioned, or in combination with a solution treatment. Such a combination materially increases the alloy's yield strength, tensile strength and hardness, but at some sacrifice of ductility.

The temperatures specified for the solution treatment and precipitation treatment of some heat-treatable casting alloys are given in the accompanying table. Precipitation treatment, with proper regulation of time and temperature, is also used to minimise the tendency of castings to growth when they are subsequently used in service at elevated temperatures. Rapid heating during treatment will go far to prevent excessive growth of this character.

The Forging of Aluminium Alloys

By a Special Contributor

The fundamental procedure and principles of the forging of aluminium alloys are briefly outlined, and a comparison made with similar operations for steel. Metallurgical factors of importance in forging aluminium alloys, together with various operations involved, forging technique and equipment, are discussed. The work is of a highly specialised nature.

FORGING, when referring to aluminium, is the operation of rapidly deforming a bar or billet above the re-crystallation temperature within the soft range of the metal by hammering or pressing, to result in a semi-manufactured product of a shape quite close to that of the finished product. In this operation both the form and the section are affected, in contrast to stamping, in which the section only is modified.

Aluminium Alloys and Steel Compared

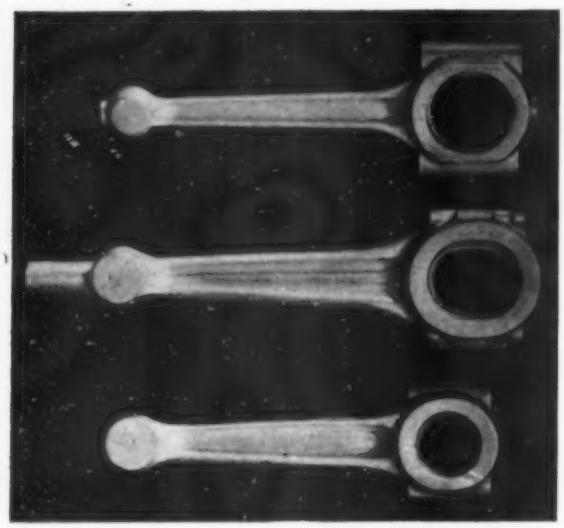
Forging by hammering or pressing is mainly restricted to structural metals, such as steels and strong aluminium alloys, whereas stamping and upsetting is used for most industrial metals, iron, alloy steel, brass, bronze, copper, aluminium, etc. The forging of aluminium alloys does not differ substantially from that of steel in so far as it takes place at an elevated temperature using similar forging equipment. However, the temperature at which aluminium alloys are to be forged is appreciably lower, the temperature range narrower, and the energy required greater than for common steels. At the optimum forging temperature the resistance to deformation of the most common aluminium forging alloy (of the dural type) is about twice that required for soft steel and 1·5 that for nickel-chromium steel. In other respects of secondary importance aluminium alloys differ from steel: the heating rate for aluminium alloys does not need to be especially slow, as these alloys have not to pass through a dangerous heating zone, as is the case with steel. Prolonged heating times are not objectionable for aluminium alloys, whereas for steel, to avoid scaling, the heating time should be kept to a minimum, just long enough to bring the centre of the billet to the forging temperature. Scaling, the troublesome problem in steel since it leads to inclusion, machining difficulties, and sticking on the dies, does not take place with aluminium alloys, as at the forging temperature these alloys remain bright and are practically unaffected. The finishing forging temperature in aluminium alloys is less critical. It rarely happens that this temperature is kept too high, and normalising is not necessary should too high a finishing temperature have been used; while for steel, too high a finishing forging temperature is not always compatible with a fine-grained structure throughout the forging. The danger of internal rupture originating from slow cooling in large forgings does not seem to be such a problem in aluminium alloys, where the forging temperatures are appreciably lower. A drastic heat-treatment, objectionable for large steel forgings, is standard for aluminium alloys. Cold straightening operations which can hardly be performed on steel after forging, are practicable and frequently resorted to in the case of aluminium alloy forgings.

Metallurgical Factors in Forging Aluminium Alloys

It has been stated that steel forging is 90% mechanical and only 10% metallurgical, while in aluminium alloys the proportion is reversed. The metallurgical factors which control the forging of aluminium alloys are: (1) Pre-heating; (2) grain refining in roughing; (3) forging temperature range; (4) heat-treatment; (5) straightening after quenching. The pre-heating time should be sufficiently prolonged to allow for the slow heating rate of aluminium alloys, as insufficient pre-heating may be responsible for cracks. Over-heating of aluminium alloys is of a different nature from that in steel, and is less to be feared, as aluminium alloys require an upper forging temperature well below the burning point—i.e., the temperature at which partial melting occurs. Such a partial melting, which would result in a number of small cracks, would take place only if the alloy were accidentally heated to some 50° or 100° C. above the upper forging temperature. The pre-heating medium for aluminium alloys is either air or salt baths. The first, most commonly used, may lead to greater oxidation of the surface of some aluminium alloys, whereas salt bath heating is more likely to cause blisters than the air furnace.

The grain refining by preliminary forging of aluminium alloys should be more pronounced than for steel in order to reduce preferential direction of properties and to result in the highest possible resistance to alternating stresses. The upper forging temperature in aluminium alloys is not limited by scaling, but rather by hot shortness, as these alloys all possess a brittle range below the point of complete solidification; the upper forging temperature should thus be kept reasonably below the critical temperature of this brittleness. However, no hard-and-fast rule can be laid down, and the optimum upper forging temperature is better arrived at by trial. The die should be kept heated above 100° C. in order to prevent any loss of heat when the light metal billet comes in contact with the die. This heating is all the more important, as aluminium alloys are to be

Stacks of radial aero engine crankcase stampings.



Courtesy of High Duty Alloys Ltd.

Drop-stamped motor-car connecting rods in RR56.

forged at relatively low temperatures and within narrow limits. The finishing forging temperature in the case of aluminium alloys is to be kept within the critical range of the alloy to produce a fine grain and thus enable the forging to respond readily to heat-treatment. This finishing temperature is limited simply by the stress to which the equipment and die may be submitted with safety.

The solution treatment temperature will vary with the type of alloy and the size of the forging, and is usually to be adhered to within 5° C. The quenching medium may be hot or cold water, depending upon whether the best resistance to corrosion or the minimum amount of internal stresses is to be obtained. Quenching medium at room temperature affords the best resistance to corrosion, and is preferable for small forgings; hot water, giving lower internal stresses, is preferable for large or complicated forgings. Immediately after quenching, aluminium alloys are relatively soft, and any straightening operation may be performed before further hardening takes place. The ageing time and temperature depend upon the particular alloy, since some aluminium alloys used for forging harden spontaneously at room temperature after a few hours and are characterised by a low-proof stress to tensile strength ratio, while others receive an additional heat-treatment at between 150° to 200° C., and are characterised by higher elastic properties.

Various Forging Operations

The sequence of operations in hammer and press forging aluminium alloys is roughly as follows:—(1) Pre-heating the bar or billet to the upper limit of the forging temperature. (2) Roughing by means of hammering, pressing, or extruding to break down the dendritic cast structure, to reduce the grain size and to ensure a uniform fine structure in all directions of the bar or billet. This roughing requires more care and experience for aluminium alloys than for steel, in view of their reduced plasticity. (3) Preliminary shaping by hammering, pressing or rolling, resulting in a shape closer to that of the semi-manufactured product. This operation may be performed in several stages. (4) Die forging by hammering, pressing or upsetting between a set of dies to produce a shape as close as possible to that of the finished product. This operation also may be achieved in successive stages. (5) Trimming to eliminate the flash—i.e., the cast metal forced out between the die in completely filling the impression. This trimming is done either hot or cold, depending upon the forging-shop facilities, as aluminium alloys are not likely to fracture if cold trimmed. (6) Heat-treating and, if necessary, straightening. (7) Finishing by sand-blasting, caustic dipping, tumbling, anodising or similar operations.

Forging Technique for Aluminium Alloys

For forging aluminium alloys the following rules should be adhered to:—(1) Billets with uniform grain size throughout should be used as forging material, as differences in grain size may lead to cracks. (2) The breaking down should be performed preferably by rolling or extruding. This roughing should be sufficient to break down completely the cast structure. (3) The die impression must have a polished surface to prevent sticking of the alloy. (4) The die radii must be more liberal than for steel, to promote an easy flow of the light metal. (5) Die shrinkage must be about $\frac{1}{8}$ in. per foot as is usual for steel, since although aluminium alloys have a higher coefficient of expansion than steel the forging temperature is kept appreciably lower. (6) The draft must be slightly larger than for steel, in order to facilitate the extraction of the forging from the die; a draft of about 10° or even 15° must be allowed for average and large size forgings, whereas 7° may be satisfactory for small forgings.

In view of the narrow range of forging temperatures, the die must be accurately pre-heated to avoid any unnecessary cooling of the stock on the die. Both dies should be abundantly lubricated with thick oil, although some forging shops are working without any lubricants.

Forging Equipment and Dies

The equipment used for the forging of aluminium alloys consists of the hammer, the press, and the upsetting machine. The hammering differs from the pressing, in that pressure is applied by means of successive short blows and is relieved before the metal has fully yielded, whereas the press acts by applying a static pressure on two sides of the billet; the upsetting machine applies a static pressure on the billets in three directions. The means by which the hammer is lifted is used to designate the various types of hammer; the steam hammer operates by means of steam, whereas the air hammer operates by means of compressed air and in the board hammer the hammer is lifted by means of a board passing between two rollers and placed at the top of the hammer. The press is either hydraulic or mechanical, depending upon the way it is operated. The upsetting machine in the case of aluminium alloys is used only to a limited extent, and mainly for pistons.

The die requirements for aluminium alloys differ as to whether forging is done by hammering or pressing, since in the case of hammer forgings the die has to resist impact, whereas in pressing the aluminium alloy flows gradually as a plastic mass, having more time to feed the die cavity. This is advantageous, not only for the metal to be forged, but also for the die itself, and has permitted in the recent past the adoption of magnesium dies. The advantage of this material for dies is to be found in low material and machining costs, and in easier handling at the forging shop.

Main Requirements of Aluminium Alloy Forgings

The gradual demand for aluminium alloy forgings permitted a parallel development of the aluminium forging alloys and aluminium forging technique. The first alloys developed and still in use were copper-bearing alloys, of the dural type. For the production of intricate forgings, maximum plasticity under the hammer led to the adoption of low alloyed metals. The requirements for tough forgings resistant to high temperature exposure introduced special alloys of the Y alloy and Lo-Ex type for cylinder heads and pistons. Recently aluminium forgings have found increasing favour in food and chemical industries, where corrosion-resisting alloys of the magnesium silicide type have been introduced.

The main requirements for aluminium forging alloys may be enumerated as follows: (1) Plasticity at the working temperature; (2) wide temperature range for forging; (3) amenability to heat-treatment; (4) high resistance to various forms of stresses; (5) stability of dimensions; (6) good resistance to corrosion. The

(*Continued on page* 134.)

Modern Practice and Developments in the Extrusion of High-Strength Light Alloys

By R. Worsdale

It is doubtful whether greater progress has been made in any other branch of the aluminium industry in recent years than that associated with the extrusion of the high-strength light alloys. The process has assumed increasing importance as a result of developments in aircraft construction and in the construction of certain road transport vehicles, and a brief outline of the technique employed in the process, given in this article, is both interesting and informative.

IN view of the rapid development over the last six years in the use of high-strength light alloy extrusions, particularly for aircraft and transport uses, a brief review of their manufacture may interest those not already familiar with the methods employed.

Briefly, the extrusion process consists " of forcing metal, heated to a plastic state, through dies by pressure."

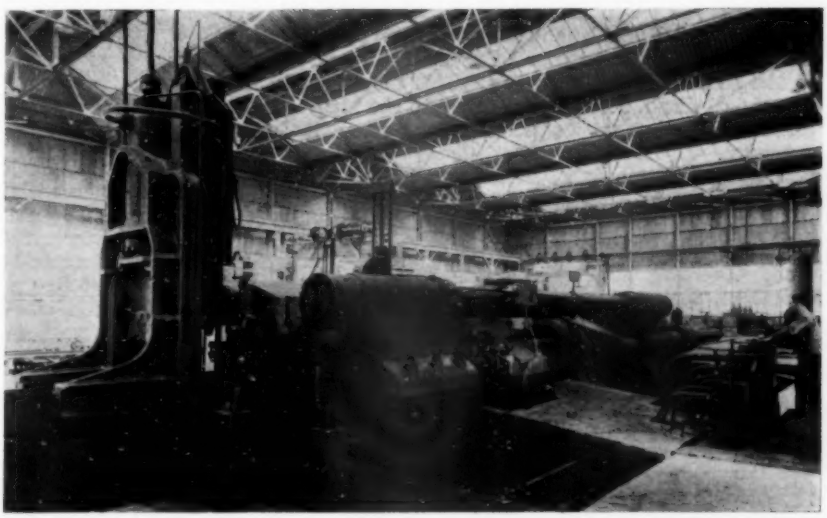
Taking the stages indicated by this definition, it is apparent that some form of press is used. For light alloys experience has shown that horizontal hydraulically operated presses are the most satisfactory. Vertical presses are sometimes used for small sections and for tubes, having the advantage of limited floor space, but their power is necessarily limited. The power necessary to operate them is supplied either by the gravity or weight-loaded accumulator, or, more generally now, by the air hydraulic accumulator. The latter consists of large cylinders, known as bottles, usually installed in threes. Two hold compressed air at a pressure of 4,500 lb. per sq. in., which is continually acting on water in the third bottle. Pressure is kept constant during operation by hydraulic pumps.

Hydraulic extrusion presses, though varying vastly in design and construction, are basicly identical. They consist of a container which receives the preheated ingot or billet to be extruded; the die, a pressure cylinder, and ram. The billet to be extruded is placed in the container, which is closed at one end by the die and at the other by a pad or pressure disc. Pressure is applied to this disc by the pressure cylinder, through the ram, the metal under this pressure being forced to flow through the die, and take the contour to which it is cut.

There are two methods of extrusion—the direct and the indirect (or inverted). With the direct process the container and the die are stationary and the billet to be extruded is pushed by the ram through the container. In the inverted process the ram is stationary, and the container and die are pushed against this ram, which is hollow, so that the billet during extrusion does not move. The latter process is seldom used, as it necessitates a hollow ram, and consequently only a small area of section can be extruded, due to the small cross-sectional area of the bore of the ram, since it must be hollow to receive the extrusion.

The Press Equipment

Horizontal extrusion presses vary in size from approximately 250 tons to 6,000 tons. Those in most common use to-day are generally between 1,000 and 3,000 tons, although for sections of large size and weight, presses of approximately 5,500 tons have been installed to meet current needs. The container consists of a forged steel circular body having an inserted liner made of nickel-chrome-tungsten heat-resisting steel, the latter being shrunk into position under pressure. This container, when mounted in the press, is surrounded by a chamber for heating purposes, the heating being supplied by gas or electricity. The ram, which is mounted in the pressure cylinder, is free to move horizontally backwards or forwards, and is actuated by the hydraulic valves which are controlled by the pressmen. By the use of hydraulic pressure an even flow can be maintained, *and it can be regulated to very fine limits, which is particularly necessary for the extrusion of light alloys.*

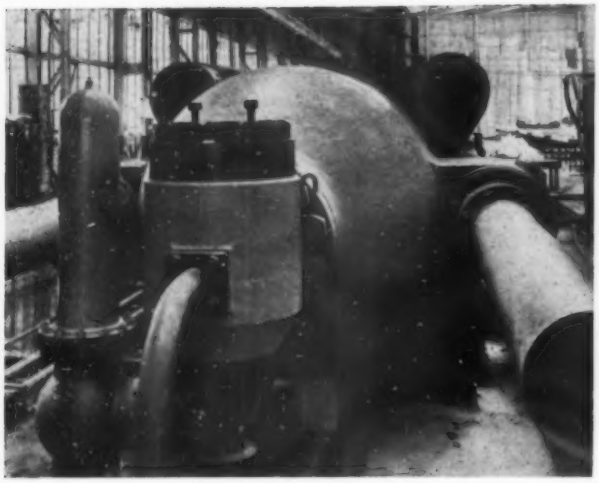


Side view of 5,500 ton extrusion press showing control platform.

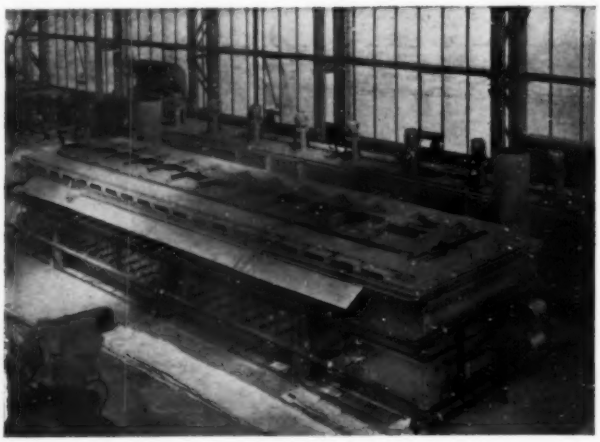
The die, which is mounted in a die-head attached to a slide, is located at the opposite end of the container to that at which the ram enters, and is held in position during extrusion by a hydraulically operated wedge.

The die-head holds the die-plate, holder and bolster, the two latter being necessary to support the die-plate during extrusion and prevent fracture owing to the heavy pressure employed. The preparation of the die-plate is most important. On its correct cutting depends to a great extent successful extrusion of the particular section desired.

The die-plate, a machined disc of nickel-chrome-tungsten steel, has inscribed on one of its faces the contour of the section, which is taken from a previously made steel templet. The die is cut through the plate in the normal manner, but the whole art of die making is in the allowances made for the bearings, to ensure an even flow of metal during extrusion through all sections of the die. Were these bearings not made correctly the extrusion would be irregular, the metal taking the line of least resistance, and in a section of unequal thickness the metal would flow at a



Rear view of 5,500-ton extrusion press.



By courtesy of Incandescent Heat Co., Ltd.

Gas-fired salt bath for solution heat-treatment.

quicker rate through the thicker to the detriment of the thinner portions. These bearings are varied according to the section, and thereby ensure an even flow of metal over the whole area of the section. Herein lies the skill of the die designer.

Die-plates for aluminium alloys are cut square, but for magnesium alloys slightly radiused dies are necessary. All dies are relieved after the end of the bearings. Dies are highly polished when completed—every file mark left in the die is repeated in the extrusion, besides adding to the die wear. The die-holder and bolster are cut similarly to the die-plate, except the contour is larger to allow easy egress to the section during extrusion. This die assembly fits into the die-head, fitting accurately into the mouth of the container, so that no metal can escape round it during extrusion.

Preparing Extrusion Billets

Extruded sections are produced from circular chill-cast ingots, known as "billets." These vary in diameter and length according to the size of press, and container to be used. To reach the "plastic state" referred to in the definition, they are placed in electrically or gas-heated air-circulated furnaces, held at the extrusion temperature of the particular alloy to be extruded. The temperature varies with different alloys, but usually is between 380° and 480° C. The soaking time varies from 6 to 10 hours, depending on the size of billet involved. The temperature and soaking time are important, as will be shown later. The preheating furnaces are usually operated by push-button control with chain conveyer hearths. Some are fed manually, others mechanically, again depending on the size and weight of the billet. On discharge from the furnace prior to entry into the press container, they are either manually or mechanically handled.

When in the container the billet has behind it a metal pad, known as a "pressure disc." This disc fits the container with small clearance, and is necessary to obviate metal flowing back over the stem of the ram during extrusion. Against the rear face of the disc the stem of the ram operates. Were it not for the pressure disc, the stem would embed itself into the soft metal of the billet and could not be withdrawn after the extrusion cycle is completed. Once the pressure is applied, the extrusion proceeds at a predetermined rate of flow until nearly all the billet has been extruded through the die. A small portion of the billet is left for practical reasons, to which later reference will be made, and is referred to as the "butt" or discard. This is sawn off and the extrusion drawn through the die, cut to convenient lengths for handling and sent for heat-treatment.

Flow of Metal

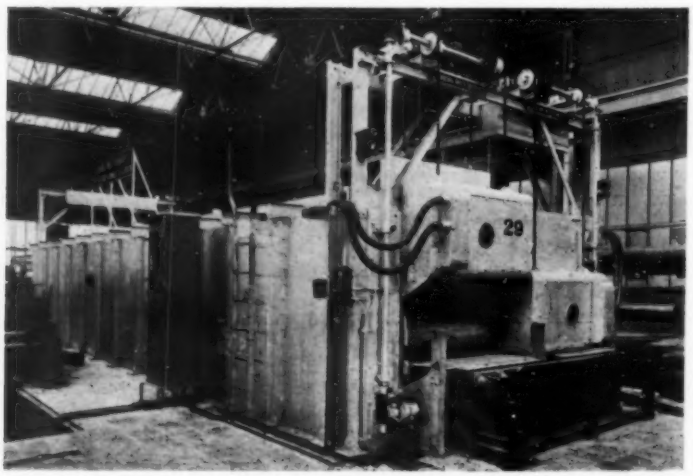
Those metallurgically minded may be interested in the flow of metal during extrusion, particularly using the direct method. Contrary as it may seem, all the metal adjacent

Die plates.

Die assembly.

Electrically operated die-heating furnace for large-size billets.

By courtesy of G.W.B. Electric Furnaces Limited.

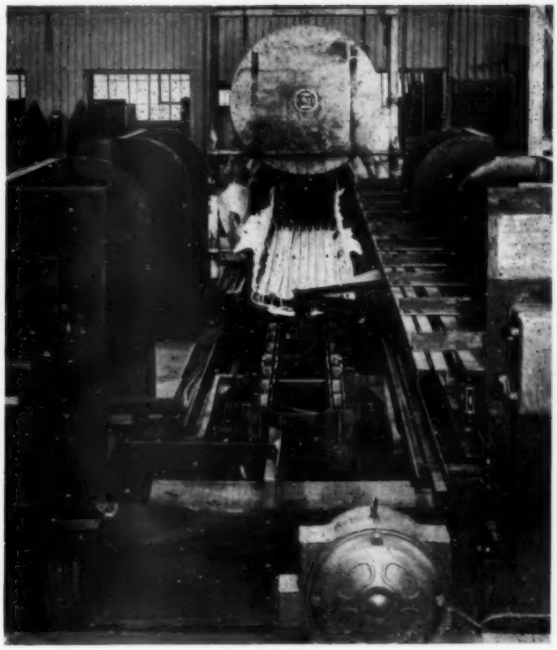


to the die face is not forced through the die, only that directly opposite to the die aperture flowing through. As the metal is under pressure, and cannot expand outwards, being confined in the container, in in order to move at all it must flow to the rear and then down the centre.

If care is not taken during the extrusion, what is known as "coring" or "piping" will be present in the finished section. This phenomenon, which cannot be entire-eliminated, controls to some extent the length of discard allowed, so that the extruded section is perfectly sound throughout. All bars and sections of reasonable thickness are very carefully examined for " coring " during finishing operations, both visually and by etching, and any defect found eliminated.

By courtesy of Electric Resistance Furnace Co., Ltd.

Two vertical solution heat-treatment furnaces.



Solution heat-treatment furnace, showing quenching gear.

During extrusion the metal is changed entirely from the cast to the wrought structure. By reason of the flow above referred to, it is turned inside out, and all the metal in a given billet receives a certain amount of work. In practice the metal in the first few feet of any section does not receive the same amount of work as the later and final portions, and therefore do not give the necessary properties required when heat-treated. Consequently, these are cropped off.

Rate of Flow

The speed of extrusion—or rate of flow through the die—at which extrusion is carried out is extremely important, as is the temperature of the metal. These two factors have a very definite relation, and unless both are carefully calibrated with the particular alloy involved, unsatisfactory mechanical properties will result in the finished section. In addition, the finish will be poor. Pearson* has carried out some interesting experiments in this direction, using the inverted method. All the high-strength aluminium base alloys contain various other metals as hardeners, notably copper, nickel and magnesium, in varying amounts, which when correctly extruded and heat-treated give the desired properties. The presence of these hardeners renders most alloys tough at extrusion temperature, and therefore great pressure is necessary for extrusion. This pressure in turn generates frictional heat between the die and container, and therefore the greater the speed the greater the heat generated. This rise in temperature during extrusion must be very carefully watched. It must not be allowed to rise beyond a predetermined limit, otherwise the material will be spoiled.

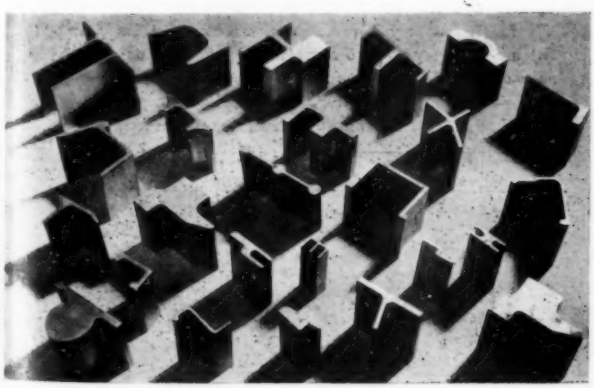
In works practice, particularly during the present period of activity, when the utmost production is required, the temperature and speed are very carefully calculated from experience for each alloy and rigidly maintained. Speeds of extrusion usually range from 2 ft. up to 10 ft., or sometimes 15 ft. per min. for the high-strength heat-treated alloys. The type of section being extruded also has some bearing on this point.

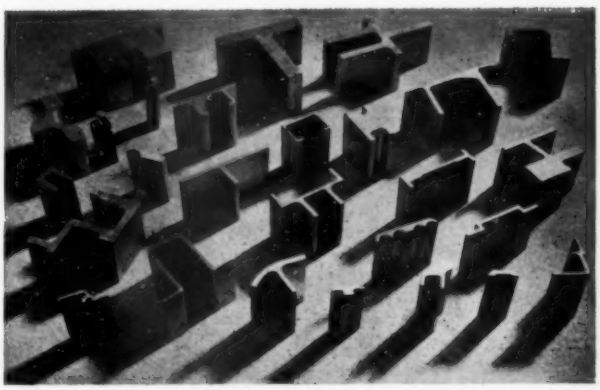
Treatment of Sections

After extrusion the sections are heat-treated. Some alloys require only the solution or quenching treatment carried out at a temperature of approximately 490° C. and then allowed to age harden at room temperature for a period of five days. Others require an additional process of artificial ageing or precipitation treatment carried out at a

*Journal Inst. Metals, **64**, 1939.

Showing typical examples of a wide range of sections now available; note particularly the varying thickness in individual sections.





lower temperature, approximately 175° C. Solution treatment can be carried out in either gas- or oil-fired nitrate salt baths or in electrically heated air-circulated furnaces.

The former are generally cheaper to install than the latter, but the electric furnace has the advantage in that operation is cleaner and there are less heat losses. There is, too, no fire hazard as with nitrate baths. Another point in their favour is that when heat-treating complex sections there is no possibility of corrosion being set up due to traces of salts being left in the interstices of the sections through insufficient washing.

The electric furnaces used are specially designed for the purpose, producers of sections usually incorporating their own ideas as a result of experience gained, in conjunction with the furnace builders. They are usually circular in shape, brick-lined, and are mechanically charged. The air-circulating fans are provided, and in the most modern types one large high-speed fan is placed at the end of the furnace and provides for rapid heat interchange and consequently less likelihood of local overheating. Their size and capacity depends on the type of section to be heat-treated, and the load. A water quench tank is situated at the discharge end of the furnace. The load on withdrawal is immersed complete with cradle in the quench tank, this operation being performed mechanically. The time lag between withdrawal from the furnace and quenching should be as short as possible, in order to obtain the optimum mechanical properties.

On quenching, distortion of the sections takes place. In an effort to minimise this distortion, which with some sections is severe, vertical furnaces have been built. In them the load is hung in the furnace, the fan being in the base, which is removable. On quenching the load is dropped into a vertical quench tank situated immediately beneath the furnace. In operation these furnaces have proved to be extremely efficient, particularly with large complicated sections, which are now used in vast quantities in aircraft construction. They increase production, due to the saving in time required subsequently for straightening.

After quenching the sections are straightened, and corrected to remove the distortion. This straightening is carried out in the first instance on hydraulically operated stretching machines, the section being mounted either in mechanically or pneumatically operated jaws, one end of which is fixed, and the other end is mounted on the head of an hydraulic cylinder. This cylinder is so operated as to pull the section, and in doing so removes the majority of kinks or bends.

This stretching process has to be carefully performed, otherwise the section will be stretched too much and the ultimate elongation affected, and its thickness reduced below the permissible limit, therefore rigid control is necessary. Stretching alone, however, does not in every case take out all the local kinks and correct the angles. In some instances, such as channels and " I " beams, sections may not be within the permitted dimensional tolerances along their entire length. Resort must be made to local correction. Such sections are therefore carefully pressed to shape at those points where necessary until the whole length is within the tolerances allowed.

Subsequent to straightening, sections manufactured in those alloys needing it are artificially aged. Visual inspection and mechanical testing are then carried out.

Increasing Applications

The use of extruded sections in high-strength alloys for stressed parts increased phenomenally during the past six years. It is true to state to-day that there are few industries which do not or cannot use them in some way or another. The aircraft industry has quite naturally made the greatest use of the facilities for production of varied types which have been made available by manufacturers. Initially, only sections of simple contour, such as plain angles, tees and channels, were generally produced. To-day a vast variety of sections are in normal production, many of which are complicated in shape. They do, however, effect great saving in weight and production time. Several sections which may have previously been produced from drawn strip, can, by extrusion, be combined together into one section, and thereby save rivetting. Similarly, sections need not be of equal thickness throughout, as rolled or drawn sections must be. The mass of metal can be placed where most needed and reduced at less important points. This factor alone is of inestimable use to designers, and they have taken full advantage of it. The fine limits to which they are now produced also renders machining operations unnecessary in many cases.

The size of sections produced varies from those which can be inscribed in a 1 in. circle up to 16 in., in weight from one-tenth of a lb. per ft. to 25 lb. or heavier in some cases. The finished heat-treated length of any section is governed by the size of billet used and heat-treatment facilities at manufacturer's works.

From the foregoing, it will be appreciated that it is difficult to define the limitations of extrusions, but any potential user having a rudimentary knowledge of their production can quite readily use it in his designs, and can obtain, from the several manufacturers in the country, assistance and advice on any particular problem encountered.

While for the moment all interest must of necessity be centred on the Defence Service requirements, a vast store of knowledge and technique is rapidly being accumulated—not only on the methods by which complicated sections can be produced readily, but also on their behaviour under strenuous conditions of service. This knowledge will sometime be available for all applications to many other spheres of industry, and the use of extrusions will, in consequence, be greater and more far-reaching in their effect on design than is possible at the moment.

Chemical Analysis of Aluminium and its Alloys

THE volume in which the methods of analysis, developed and standardised by the British Aluminium Company's Laboratories, were set out for general information was greatly appreciated by the light metal industries, and has become regarded as a standard work on the subject.

Since the publication of this work additional methods of analysis have been developed and standardised in the Company's Laboratories; these have been published in the form of a brochure which is designed to fit into the back of the existing volume. The new methods of analysis are issued as two addenda—the first dealing with the determination of antimony, bismuth, niobium and zinc, the latter a replacement method, and the second addendum dealing with the analysis of super-purity aluminium, aluminium bronze, and aluminium skimmings and dross.

Copies are available on application to the British Aluminium Co., Ltd., Raven Hotel, Shrewsbury, Salop.

THE Proprietors of the British Patent No. 465313 for Refractory Product and Process for its Manufacture are prepared to enter into negotiations for the sale of the patent or for the grant of licences thereunder—any enquiries to be addressed to Carpmaels and Ransford, 24, Southampton Buildings, London, W.C.2.

THE Proprietors of the British Patent No. 474716 for Low Temperature Brazing Alloys for Uniting Aluminium Alloys are prepared to enter into negotiations for the sale of the patent or for the grant of licences thereunder—any enquiries to be addressed to Carpmaels & Ransford, 24, Southampton Buildings, London, W.C.2

Working Aluminium and Aluminium Alloy Sheet

By a Special Contributor

The fabrication of aluminium and aluminium alloy sheet involves such operations as bending, flanging, spinning, pressing and forming by means of a drop hammer. The material is worked cold. In this article attention is particularly directed to the working of the single heat-treated types of alloys.

THE development of sheet aluminium alloys during the past few years has to a great extent completely altered the procedure of design. Whereas in the past materials were chosen solely for the ultimate requirements of the finished article, the alloys now available offer a range from which may be selected materials which will fulfil certain requirements and at the same time lend themselves to various methods of production. The production of articles from sheet is usually carried out by working the material cold, and may include such operations as bending, flanging, spinning, pressing and forming by means of a drop hammer.

The alloys of aluminium can be divided into two groups, strain-hardening alloys which acquire their mechanical properties as a result of cold working, and the heat-treatable alloys. Those in the second group may be sub-divided into two further categories—usually referred to as single heat-treatment and double heat-treatment types. It is proposed in this article to deal mainly with the single heat-treated types of alloys.

Dealing first with the single heat-treatment group, the alloys at present in use are those to specifications BSS 5 L 3, BSS L 38, DTD 390, and DTD 275. These alloys are usually supplied in the fully heat-treated condition, and in order to carry out forming operations it is preferable to solution heat-treat the material and form within one hour of such treatment. During the first hour immediately after solution heat-treatment, the metal is comparatively soft and does not harden to its fullest extent until about 5–6 days have elapsed. No further heat-treatment is necessary, as such alloys age harden spontaneously at room temperature. For solution heat-treatment a fused salt bath is usually found to be most satisfactory, as this method ensures rapid heating and a uniform temperature which can be very closely controlled. It is essential that the material should be heated uniformly throughout without overheating.

Whilst the alloys referred to above can be made permanently soft by annealing, so that forming operations are possible without resorting to the above procedure, it should be noted that the development of full specification mechanical properties requires final solution heat-treatment which is likely to cause considerable buckling and distortion of the formed parts. This may necessitate further operations and give rise to difficulty in attaining the desired final shape or dimension.

As practically the whole of the light alloy sheet production of the single heat-treatment type is supplied in the finally aged condition, annealing or permanent softening, if required, must be done at the works where the forming operations are to be carried out. This annealing process, if maximum softness is to be obtained, is a somewhat long operation, for it is recommended that after the sheets to be softened have reached the prescribed annealing temperature, the furnace be maintained at this temperature for at least one hour, and then allowed to cool off at the rate of not more than 15° C. per hour until the temperature has dropped to 270° C., when cooling in air is then permissible.

BEND RADII FOR FORMING TOOLS.
T = thickness of Sheet.

Specification.	Temper.	Sheets 18 S.W.G. and thinner.		Sheets thicker than 18 S.W.G.	
		Less than 120° Bend.	Over 120° Bend.	Less than 120° Bend.	Over 120° Bend.
BSS 5 L 3	Annealed	½ T	1 T	½ T	1 T
BSS 2 L 38. DTD 275. DTD 390	Within 1 hour of solution heat-treated	½ T	1½ T	1½ T	2 T
	Heat-treated and aged	2 T	3 T	2½ T	3 T

Approximate thickness in Inches.

Specification.	Temper.	0·016.		0·032.		0·064.		0·125.		0·187.		0·250.	
		90° Bend.	180° Bend.	90° Bend.	180° Bend.	90° Bend.	180° Bend.	90° Bend.	180° Bend.	90° Bend.	180° Bend.	90° Bend.	180° Bend.
DTD 351	Annealed	OT	OT	OT	OT	OT	O–IT	OT	O–IT	O–IT	½–1½T	½–1½T	½–1½T
	Solution H.T.	O–IT	O–IT	O–IT	½–1½T	½–1½T	½–1½T	½–1½T	1–2T	1–2T	1½–3T	1½–3T	2–4T
	H.T. and aged	1½–3T	1½–3T	2–4T	2–4T	3–5T	3–5T	4–6T	4–6T	4–6T	5–7T	5–7T	5–7T

TABLE OF HEAT-TREATMENT AND ANNEALING TEMPERATURES.

Material Specification.	Annealing Temperature.	Solution H.T. Temperature.
BSS 5 L 3. DTD 275 BSS 2 L 38. DTD 390	Heat-treated and aged 425° C. Work-hardened 340° C.	490° + 10° C.

This slow cooling is usually accomplished by shutting the furnace off when the necessary soaking time, at the annealing temperature, has elapsed.

It will be appreciated that the correct annealing practice of light alloy sheet in the finally heat-treated and aged condition is not a commercial production proposition and should be avoided if possible.

An exception to the former recommendations must be made where forming is to be carried out by means of an hydraulic press employing a rubber pad in place of the customary metal punch. Where one of the heat-treatable types of light alloy sheet is specified it appears essential for fully annealed material to be used.

A table of heat-treatment and annealing temperatures for the light alloy sheet specification at present in general use is given below, together with approximate soaking times. These will vary slightly with the type of furnace used and the load to be treated. It should be noted that the annealing temperatures depend on whether the sheet is in the finally heat-treated condition or has been work-hardened from the annealed condition during previous forming operations.

TABLE OF SOAKING TIMES FOR SOLUTION HEAT-TREATMENT.
TIMES OF IMMERSION IN NITRATE BATH.

Gauge.	Time, Minutes.	Gauge.	Time, Minutes.
26 and under	6—10	10 ..	22—28
22 ..	10—14	6 ..	28—34
18 ..	13—19	3 ..	30—38
14 ..	16—22		

Where it is not desired to carry out either annealing or solution heat-treatment before forming, due to production considerations, and where the parts to be formed are such that they cannot be formed from the sheet in the finally aged condition, a solution to the problem may be found in one of the double heat-treated alloys.

A notable example is specification DTD 351, which covers Alclad NA 21S Alloy. Material to this specification is normally supplied in the solution heat-treated condition in which its ductility is such that it can readily be formed without further heat-treatment or annealing. The subsequent low temperature ageing process, which is 165° C. for not less than 10 hours, does not cause buckling or distortion. For the satisfactory working of aluminium and its alloys press and forming tools should have as smooth a finish as possible, final honing and polishing being carried out in the direction of tool travel. Too much attention to this point cannot be given, as aluminium and its alloys have a tendency to " pick up " on steel. If possible, tools should be finally hardened. It is essential in most cases that a suitable lubricant be used and a mixture of lard oil and paraffin or a neutral soap are usually found satisfactory.

Spinning Aluminium Sheet

The spinning process is mainly confined to pure aluminium and the strain-hardened types of alloys, although the heat-treated alloys can also be worked in this way. The lubricant generally used is tallow, lighter types of lubricant tend to fly off the work during spinning. Recommended spindle speeds are as follows :—

Diameter of Chuck.	Speed R.P.M.
3—6 in. ..	2,000
7—10 in. ..	1,500
11—14 in. ..	1,000
15—20 in. ..	500

Spinning chucks are generally made of lignum-vitæ, or of steel when large quantities are to be produced. Section chucks made from light alloy can be used to advantage and have long life. When consideration is given to the weight handled by the spinner in dismantling and assembling the chuck, it will be appreciated that by using light alloy, the weight of which is approximately one-third that of steel, a considerably greater production of articles is possible with much less fatigue.

The Machining of Aluminium

THE successful machining of aluminium and its alloys requires in most instances that certain changes be made in the shape of tools used customarily in the machining of steel or brass. The extent of these changes depends largely on the character of the work undertaken, the alloy used, and machine tool employed.

Cutting tools commonly used in machining free-cutting brass usually have little, if any, top and side rake ; those used for steel have some top and side rake, but for aluminium and the majority of its alloys the tools should have appreciably greater top and side rake than those used for steel, and, in addition, should have very keen edges, obtained by grinding with fine abrasive wheels, supplemented in all cases by hand-stoning with an oil-stone.

The front clearance of a tool for machining aluminium should be about 6° to 8° ; the top rake from 30° to 50°, making the total angle of the cutting edge of the tool from 35° to 55°. A side rake of from 10° to 20° will materially assist in the cutting action of the tool. These values apply in general, but may in some cases be modified with advantage, depending on the alloy and the type of work.

It is frequently found best to set a lathe tool considerably higher on the work than when machining brass or steel ; in fact, good results have been obtained when the cutting edge of the tool is set so as to be on a diameter of the work, making an angle of 45° with the horizontal. This may, of course, mean considerable resetting of the tool where a large amount of stock has to be removed.

Parting tools for machining aluminium and its alloys should have from 12° to 20° top rake, and be stoned so that their cutting edges are keen and smooth. With such tools the front clearance angles should be decreased to about 3° or 4°.

An ordinary twist drill is not entirely satisfactory for use with aluminium, and a single-fluted twist drill, such as is used for the manufacture of hard-wood furniture, is often more satisfactory, or a two-flute drill having spiral angles of about 47°, instead of the usual 24°. To give the best results hand and machine taps should have a spiral flute, and the spiral angles should be similar to those used in an ordinary twist drill. Satisfactory taps have been made by chasing threads on annealed high-carbon twist drills, followed by retempering and finishing. Slightly oversized taps often assist materially in maintaining the required dimensions of threads in aluminium and its alloys, as aluminium, on account of its low modulus of elasticity, " recovers " more than steel after tapping operations.

There are, however, certain free-cutting aluminium alloys, such as the Northern Aluminium Company's alloy NA 29S, which can be machined satisfactorily with tools similar to those used for free-cutting brass. This alloy gives short chips and can be machined at high speeds with ease, giving an excellent finish when using tools normally used for brass.

Some of the alloys of aluminium will machine successfully without any lubricant, but in order to obtain the best results some form of lubricant is desirable. A soluble cutting oil has been found to be quite satisfactory for general use, although for heavy cuts and slow speeds, such as in roughing work or tapping, pure lard-oil has been found to give good results. Cutting compounds having a paraffin base, such as are used in machining brass, are quite unsatisfactory for machining aluminium.

There is, naturally, a tendency for the stock to heat up when using coarse feeds, and as the linear coefficient of expansion of aluminium is rather high, warping of the work or excessive friction on the centres is likely to result in the case of engine lathe work. An adequate supply of coolant is therefore highly desirable. When appreciable heating of the work does occur, the stock, of course, should be cooled before callipering and finishing to size in order that accuracy of dimensions is obtained.

The Polishing, Plating and Anodising of the Aluminium Light Alloys

By E. E. Halls

The constantly growing field of technical applications of aluminium and its alloys has made it increasingly necessary to be able to vary the surface, provide for such requirements as decoration, protection from chemical, physical and mechanical action, or combinations of these requirements. In this article the author discusses briefly practical methods of surface treatment.

THE members of the aluminium series of light base alloys, including aluminium itself, have their own peculiarities which contrast them with most other groups of engineering metals, and which render processing rather specific with respect to actual treatments or precautions to be observed. They are all relatively soft, so that in processes of mechanical surface preparation much thought is warranted in choice of files, grinding wheels and polishing buff, as well as in the use of these. They are all highly reactive metals in the chemical sense, and in consequence consideration is demanded to materials used for precleaning, and special attention is essential to their passage through elect o-plating processes. Under many conditions of service the aluminium alloys are relatively non-corrodible, this being due to the acquisition of a superficial layer of oxide. In other circumstances the oxide film is inadequate to act as a protective coating and the highly reactive nature of aluminium asserts itself, with rapid deterioration of the component if some additional safeguard is not provided. Hence a full knowledge of the conditions to be encountered in the field as well as a sound knowledge of the behaviour of the alloy are essential if rational protection is to be provided without unnecessarily going to the expense of the most complete protection.

On the electro-chemical side there are two groups of finishes which give excellent service, and from which choice can be made according to circumstances. The first of these comprises the electro-plate processes, which, in effect, consist of the orthodox plating-shop methods with appropriate controlled modifications to suit aluminium. The second consists of the anodic treatments, by means of which that self-healing natural oxide film acquired by aluminium and its alloys is strengthened and its resistance enhanced to cater for drastic exposure conditions. When processes from either of these groups are applied to castings, pressings and machined components, or to structural work, all the surface blemishes such as file marks, rolling striæ, casting defects, and the like, tend to become visually enhanced, and the more obvious irregularities therefore detract much from appearance. In some instances this is of no consequence; in many, however, decorative effect is of equal importance with protective value, and mechanical preparatory operations become essential for conditioning the work surfaces prior to finishing. This article, therefore, proposes to give, briefly, practical notes on methods of polishing, plating and anodising.

Polishing

Work arriving in the industrial metal-finishing shop is usually in a condition ready for polishing, which embraces two operations, one a cutting process with abrasive on a a felt or canvas wheel, the other other a polishing process using a soft compound on a soft mop. Heavier operations of fettling castings, removing weld surplus and deburring are generally carried out in the machine shops. These latter are outside the present scope, but it must be stressed that the final polishing cannot be achieved economically or efficiently if these earlier operations are not properly controlled. The points to be borne in mind are the softness of aluminium, the ease with which it drags over to promote objectionable inclusions of grease or abrasive, and the manner in which it fills files and glazes wheels. Single-cut files; open-grain wheels, not too coarse; and optimum speeds—these are the salient features.

The work in the polishing shop will depend upon the origin of the component. Sand castings will require an additional and coarser cut than do die castings; articles from hard-sheet material may only require one operation. Operating through a wide range of grits is not generally as effective with respect to final lustre, or total time, as employing a narrower range starting with less coarse. Again, the softness of aluminium alloys insists upon light pressures, and generally presupposes high peripheral speeds to wheels. The latter, in general, are to be preferred, but when the coarser grits are used it will be found that lower speeds are more successful.

The cutting operations are achieved with abrasive on sewn buff or stitched canvas wheels. Emery and alundum, set up with glue, are both used as abrasive, but experience seems to favour the latter. Grit sizes are chosen from the range No. 60 to No. 200. Rough castings would start with a grit selected from between No. 60 and No. 100. Die castings would use one between 120 and 200. Much pressed sheet work would use No. 180 grit on a felt wheel, followed by buffing, or would merely receive a buffing with a wheel dressed with tripoli compound. Regarding circumferential speeds of wheels, values from 2,000 to 7,000 ft. per min. are used. Actually, figures 4,000 for the coarser grits and 6,000 for the finer grits may be taken as a reliable guide. Some operators use lubricant, either tallow or a mixture of tallow and oil, but when this practice is resorted to, the amount should be minimised to prevent its occlusion to the work. At all stages it is well to remember to keep pressures light, to watch for glazing of the wheel, and never to use wheels employed for other metals.

The finishing stage of polishing does not have the powder glued to the wheel, but it is applied to a softer type of wheel, first from a grease-bonded block and then as a dry compound. Tripoli is almost invariably used as the grease compound, and care should be exercised to purchase a suitable grade. It is available not only in several degrees of coarseness, but also several grades, with respect to uniformity. After the grease treatment the dry polishing or "colouring" uses Vienna or Sheffield lime (which, in effect, is a natural chalk in lump form). This brings out the natural colour of the metal, and aids materially in removing grease. Speeds of 6,000 to 10,000 ft./min. are used in this final operation.

Polished work may be destined for service without further protective coating. It will tend to dull and slowly corrode according to conditions, and to safeguard against this a thin lacquer coating is desirable. For this to be effective, to exhibit good adhesion, and not to change the visual appearance of the job, care in selection is required. One of the best of materials is a low-consistency cellulose-synthetic combination lacquer, sprayed to give a very thin film; it rapidly air dries.

Electroplating

Work finished by polishing as above is in a clean condition and can be racked and jigged ready for the plating line. Work for plating without polishing needs to be cleaned to free it from swarf and machining oils. Solvent degreasing in liquor-vapour trichlorethylene plants, or treatment in a hot, mild alkali, such as 2 oz. soda-ash and 2 oz. sodium-meta-silicate per gallon of water, affects this.

The fundamental difficulty in plating aluminium lies in the fact that when immersed in normal electrolytes, and before contact with the bus-bar can be made, chemical reaction occurs with the dissolution of aluminium and the deposition of the metal, nickel, copper, cadmium, etc., from the solution as a non-adherent coating, which prohibits proper adhesion in the electro deposition that follows. Added to this is the presence of the natural oxide film, which must be removed, and not allowed to reform, prior to plating. In effect, therefore, the work, after wiring or racking, must pass to the plating line, consisting of the following series of operations: (1) light degrease; (2) water rinses; (3) pretreatment; (4) water rinses; (5) plating proper; (6) water rinses.

Before discussing these in detail a few words are justified upon the particular metal coating. Aluminium and its alloys are relatively non-corrodible in many circumstances, but easily so in others. The surfaces of articles are relatively soft, easily scratched, or mechanically damaged. Slight corrosive effect causes dulling, whitening, or a dirty tarnish: heavy corrosion produces whitish compounds, which are never so unsightly as rust on ferrous materials. The function of the plating should therefore be to preserve a neat appearance, mechanically and chemically. Neglecting the protective influence of the oxide film, which becomes inoperative under severely corrosive conditions, and viewing the problem from the electro-chemical standpoint, none of the metals ordinarily electroplated will sacrificially protect aluminium because they fall below it in the electro-chemical series (see Table I). Consequently, the easily corrodible coatings, such as zinc and cadmium, offer no advantage as they would themselves deteriorate to unsightly surfaces.

TABLE I.

ELECTROMOTIVE SERIES OF THE METALS.
(Voltage difference between metal and normal solution of its ions.)

Metal.	Electro Positive.	Metal.	Electro Negative.
Magnesium	+ 1·3	Lead	− 0·12
Aluminium	+ 1·0	Tin	− 0·14
Manganese	+ 0·8	Copper	− 0·6
Zinc	+ 0·5	Mercury	− 1·0
Iron	+ 0·2	Silver	− 1·0
Cadmium	+ 0·16	Platinum	− 1·1
Nickel	0·0	Gold	− 1·7

Nickel, however, offers some mechanical protection and retains its appearance reasonably well, particularly if covered with a thin lacquer (as recommended for polished work). The nickel covering must be a sound one with respect to adhesion, freedom from porosity, and continuity. It must, therefore, be deposited under controlled conditions, and be reasonably thick—that is, of the order of 0·0005 in. to 0·001 in. for normal purposes, and 0·001 in. to 0·0015 in. for severe exposures. Again a final flash of chromium over the nickel enables a bright polished finish to be retained for long periods, the chroming process conferring corrosion-inhibitive properties to the surface. Consequently, when designers are considering platings they are advised to select nickel/chromium, or, failing this, nickel alone. Admittedly, other platings have their purpose—thus copper or brass is used as a base for chemically coloured finishes such as china bronze or oxidised brass, and gold is used for electrical contact reasons. Even in these instances a ground coating of medium-heavy nickel is strongly commended.

Returning to the sequence of operations on the plating line, the light alkali degrease can use the soda-ash/sodium-metasilicate mixture, sodium metasilicate alone, or a proprietary product having this alkali as a base. Table II shows the compositional characteristics of the latter type.

TABLE II.

ALKALI CLEANING COMPOSITIONS.

Composition.	A.	B.	Sodium Meta Silicate Crystals.
	%	%	%
Sodium Carbonate (anhydrous basis)	50·0	—	—
Sodium Meta Silicate (anhydrous basis)	25·0	55·0	58·0
Soap (Sodium Oleate)	—	5·0	—
Water (combined)	25·0	40·0	42·0
	100·0	100·0	100·0

Concentrations of 2 to 4 oz./gal. are suitable with operating temperatures of 85° to 95° C. The silicate provides for free and thorough rinsing, which is carried out in two washes, cold and hot, without allowing drying to occur before entering the next process. The long-established pretreatments are "metal dips"—that is, immersion in a solution of heavy metal salts. The most successful used employs ferric chloride, viz.:

Ferric chloride solution S.G. 1·45	0·03 gal.
Hydrochloric acid, S.G. 1·16	0·01 ,,
Water	1 ,,

This solution is used at 90° to 95° C., and immersion time controlled to that at which gassing ceases, this being from 10 to 30 seconds. A rapid cold- and hot-water wash follows, with insertion in the nickel bath without allowing drying to commence. Some workers interpose a 10-second immerion in 10% hydrofluoric acid at ordinary temperatures, especially with high-silicon content alloys. Regarding the nickelling, some workers use the standard or the bright nickel solutions, but one more than usually heavily loaded with magnesium or sodium sulphate is to be preferred, e.g.:

Single nickel salts	26 oz.
Sodium sulphate crystals	44 ,,
Boric acid	2 ,,
Ammonium chloride	2 ,,
Water	1 gal.

This is operated at ordinary temperatures—10 to 20 amps./sq. ft.—and maintained at a *p*H value of 5·4 to 5·6. This nickel plate can be followed by a bright nickel and chromium flash, or it can be buffed up and then chromium flashed. In the latter case the buffed work must be re-degreased, water-swilled, and rinsed in cold dilute sulphuric for a few seconds, followed by water washing before introducing into the chrome vat. The chromium plating is the standard bright chrome, using 40 oz. chromic acid and 0·4 oz. sulphuric acid per gallon of water. It is operated at 100° to 110° F., with a current density of the order of 100 amps./sq. ft. Antimonial-lead anodes are used.

Recent development has been towards utilising an anodic treatment as a starting-point for plating. No commercial success can apparently be claimed, although U.S. patent 1,971,761 covers a process. This suggests an anodic film produced on the precleaned work by an oxalic-acid solution, 4 oz./gal. water, 10-minute processing at 70° F. (20° C.) under 50 volts a.c. Washing follows, then a treatment in 5% cold sodium-cyanide solution for 12 to 1 minutes. W er washing immediately proceeds, an n nickel pla g from standard or bright solutions, ved by any other plating desired. It is believed that type of procedure requires some development before adoption industrially.

nother simple procedure claimed, although no known pla s operating it can be cited, uses a sodium-zincate dip,

instead of the ferric-chloride treatment, specific gravity 1·25 to 1·4 at ordinary temperatures for 1 to 3 minutes. It is followed by water washing. If a uniform pickling effect does not result the work is then immersed in cold 50/50 nitric/sulphuric-acid mixture, washed in cold water, and redipped in sodium zincate. Water washing and plating follows. A smooth surface giving good adhesion is claimed, with suitability for direct deposition of zinc, cadmium, copper, nickel or nickel-chromium. In this connection it is interesting to note that one plant operates using a combined electrolytic degrease and pretreatment. The solution is a mild alkali containing a small percentage of zinc, and processing is cathodic for 10 to 30 seconds, so that a continuous thin film of zinc is produced on the freshly reduced surfaces. Rapid water rinsing followed by nickel plating ensues.

Another specialised process is worthy of mention. This is used for gold plating thin aluminium or duralumin components for electrical contact. Pretreatment comprises satinising by caustic soda and nitric-acid dips, water washing, and thin gold plating at 1 amp./sq. ft in a cold electrolyte composed of 1·5 oz. aurous cyanide, and 1·0 oz. sodium cyanide per gallon of water. Work is agitated, and hydrogen evolution at the work surface during deposition apparently aids reduction of any oxide film.

Anodising

Anodising is a process by means of which the naturally protective oxide film upon aluminium and many of its alloys can be strengthened. It is closely similar to electroplating processes in so far as work has to be thoroughly cleaned and may be mechanically prepared by graining or polishing, and is then treated under controlled conditions of voltage, temperature and time in a suitable electrolyte. The vital difference lies in the fact that in plating, work is made the cathode in the vat, while in anodising it is the anode. This general statement requires qualification in so far as one anodic process now commercialised uses alternating current in contrast to direct current that hitherto has been found necessary.

Three electrolytes have become commercially established, namely, chromic acid, sulphuric acid, and oxalic acid. Before briefly describing these various anodic processes, a short discussion of the treatment in general is helpful.

Anodisation produces a film by oxidation of the work surfaces. This film is tenaciously adherent, transparent or translucent, hard, extraordinarily corrosion resistant, and possesses properties of electrical insulation. In all these respects the actual degree of the quality induced is a function of the processing conditions and of the alloy treated. It is to be noted, it is the production of a film upon *aluminium* that provides these characteristics, and, consequently, the presence of alloying elements must be expected to modify them, and, in general, to exert a relatively unfavourable influence. High percentages of copper, zinc and silicon thus exert their own peculiar influences. Anodisation is consequently best upon aluminium itself, protection is at its maximum, colour and transparency of film are at their best. Local impurities, such as inclusions, will cause weaker spots or areas. The low-content manganese and magnesium alloys (e.g., 1¼% manganese, or 0·5% magnesium) are imperceptibly different from pure aluminium. Copper up to above 4% does not prevent satisfactory processing, but irregular and patchy colour may result, with marked mother-of-pearl colourings. Duralumin falls in this category. Higher copper contents are preferably treated by the sulphuric- or oxalic-acid processes. Silicon causes darkening of the film, and the standard 10% alloy anodises to a dark-purple colour. Y or RR alloys are best treated by the sulphuric- or oxalic-acid processes. The free-cutting zinc and zinc-copper-aluminium alloys containing up to zinc respond to all processes.

In general, it must clearly be borne in mind that the anodic film, by its transparency, enhances any defects existent in the surfaces treated. Hence rolling marks and and casting defects become exaggerated, so that when decorative effect is of value as well as protective quality, surface preparation must be carefully executed.

The anodic film during its formation is porous and absorptive, and at this stage can be dyed or pigmented to yield many self or variegated colour effects.

Many anodic processes have been developed and patented, but the chief and successful ones are operated in most parts of the world, viz. :

(*a*) The Bengough chromic-acid process, now apparently patent free.
(*b*) The sulphuric-acid process, covered by one group of patents.
(*c*) The oxalic-acid AC and DC processes, covered by another group of patents.

As earlier stated, precleaning, etc., is exactly as for plating, and the same applies to after-washing and drying. Racking must be given special attention with respect to electrical contact, as the anodic film is insulating, hence firm pressure must be assured, and the area contacted will not become anodised, so it must be small and as far as possible arranged to occur in a position of least consequence.

The chromic-acid process uses 3% pure chromic acid as electrolyte at 40° C. Average working conditions use a d.c. potential, gradually rising to 40 volts during the first 15 minutes, maintaining at 40 volts for 35 minutes, then rising to 50 volts over a 5-minute period, and holding there for 5 minutes. Welded steel tanks with proper exhaust and graphite cathodes are used. Heating and cooling coils to control the reaction temperature are essentials, and agitation is advocated. Practical attention is required for the avoidance of air locks or positioning work to induce gas traps. This is the longest-established and still most widely relied upon process.

TABLE III.
UNTREATED AND VARIOUSLY ANODISED ALUMINIUM ALLOY CASTINGS : BEHAVIOUR UNDER SALT SPRAY EXPOSURE.

Sample No.	Anodic Treatment.	Durability Under Salt Spray Test.
1	None	General whitening and deep attack at many points in one day.
2	Chromic Acid Bengough	A few small white corrosion spots only in 100 days.
3	A.C. Oxalic Acid	A few small white corrosion spots evident in 10 days. At the end of 100 days a number of points of attack developed, but mainly confined to edges, corners, holes and casting blemishes.
4	D.C. Oxalic Acid	A few small corrosion patches evident in five days, but no further deterioration in 100 days.
5	Sulphuric Acid	Tiny white corrosion spots developed during first few days. Marked attack on corners and edges in 10 days and condition generally rather poor in 20 days.

The sulphuric-acid process is more straightforward in utilising a constant voltage and offering a range of factors that can be varied to produce different results with respect to thickness, hardness, heat- or weather-resistance, and electrical resistivity of the film. Dilute sulphuric acid, with additions such as ethylene glycol or glycerine, is the electrolyte ; operating temperature is 15° C. to 20° C., and voltage 10 to 15 volts d.c. Provision for agitation, cooling and fume removal are as for the Bengough process. Acid concentration may range from 10 to 70%, and treatment time from 10 to 15 minutes. The washed treated work finally has to be sealed—the patents cover various methods, these being aqueous immersion treatments in solutions of boric acid or chromates. If the work is to be dyed or pigmented, this treatment, also an immersion type of process, is performed before sealing.

The oxalic processes follow along exactly similar lines, a range of concentrations, voltages and temperatures being practicable according to the results to be achieved.

The three processes give slightly different films. The Bengough tends to be light yellowish grey and opaque, whereas the sulphuric-acid film tends to be transparent, and is almost invisible in aluminium and low-content manganese and magnesium alloys. The oxalic-acid film tends to be more golden, although still transparent. Corrosion resistance is of similar order with all of them, but the flexibility of the sulphuric-acid process enables it to provide a wider range of hardnesses, higher electrical insulation, and a better range of dyed and pigmented films than does the chromic-acid process. Nevertheless, the latter is exceedingly reliable where corrosion resistance is the fundamental aim, and in the writer's opinion still demands first consideration. The oxalic-acid process is still in its infancy in this country, and, consequently, calls for more first-hand experience before truly commenting upon it. For interest, Table III gives salt-spray exposure tests results on commercial castings having the following composition, untreated and treated by the three types of process :

	%
Silicon	8·5
Copper	1·4
Iron	2·4
Manganese	0·02
Aluminium	Remainder

The silicon and copper render this treated alloy relatively prone to attack. In wrought forms, aluminium, duralumin, manganese alloys and magnesium alloys up to 7% would withstand six months of the test conditions without deterioration. Figs. 1 and 2 show photographically hard-rolled duralumin foil, only 0·003 in. thick. No. 1, untreated, after seven days' salt-spray test, was generally corroded and full of pinholes ; No. 2, anodised by the Bengough process, and after 100 days' test, showed no signs of corrosion, a little staining only. The spray test used 20% salt solution atomised with compressed air, and one day's exposure included 8 hours with the atomiser operating, 16 hours off.

Fig. 1.—Untreated surface after seven days' salt-spray test.

Fig. 2.—Anodised by the Bengough process and after 100 days' test.

The anodic processes permit of protection of most aluminium alloys under most adverse conditions, including colouring in the process, decorative effect can be catered for. Alternatively, lacquers or enamels may be used with assured adhesion.

Japanese Research on Aluminium Production

By L. Light, Ph.D.

ALTHOUGH the bulk of the aluminium produced in Japan is derived from imported bauxite which is worked up by standard methods, the industry has sponsored a considerable amount of development work in recent years, aiming at the utilisation of minerals available in Japanese or Chinese territory. As a result, several experimental plants are now in operation in which the raw material consists of alumite clay or aluminiferous schist, while promising results have been obtained in preliminary work with diaspore. Progress in this field has been reviewed by Jiro Kitawa.*

Alumite from Korea is the starting material in the Ranaka process which has been adopted by the Nippon Electric Industry Company, and involves reaction of the calcined mineral in succession with ammonia and caustic soda. In the process of Okazama, also owned by the same concern, alumite is directly treated with caustic soda. The Ranaka process yields a valuable by-product in the shape of ammonium sulphate. The process under development by the Sumitomo Aluminium Company also involves isolation of aluminium hydroxide from alumite by treatment with ammonia and subsequent conversion to sodium aluminate.

The Nichiman Aluminium Company is particularly interested in the Suzuki-Tanaka process, in which an intimate mixture of coal and clay is fused in an electric furnace to give crude alumina, which is further treated with chlorine gas after pulverisation. Some interest has also been aroused in the discovery of Arimori that calcined china clay can be treated with sulphuric acid to dissolve the alumina at ordinary pressures, whereas minerals of the type of diaspore require treatment at high pressures. According to Professor Nagai (Tokio University), diaspore is of potential interest as a source of aluminium by virtue of its ready solubility in alkali under pressures of 50 to 100 atmospheres, although it is insoluble at normal pressures. An alternative process investigated by Nagai consists in calcining an intimate mixture of diaspore and sodium carbonate at 1,000°–1,200° C., when alumina containing a trace of silica is formed. In a modification of the same process the diaspore in admixture with lime is fused in an electric furnace to give calcium aluminate, which is then converted into sodium aluminate with the aid of sodium carbonate.

An unusual raw material for aluminium which is being exploited by the Kuto process (Nitto Chemical Industry Company) is a mineral containing both alumina and phosphates found on the Luciu Islands.

The percentage compositions of some of the minerals used in these investigations are given in the following table :—

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Alkali	SO_3	H_2O
Alumite (Korea)	5—16	22—36	1—5	—	7—10	32—36	10—11
Aluminiferous schist (Manchukuo)	8—20	50—70	1—10	2—3	—	—	14—15
Aluminiferous schist (North China)	4—12	60—70	2—6	1—3	—	—	13—14
Clay (North China)	2—12	70—80	2—4	1—2	—	—	14—15

*Japanese Year book of the Chemical Industries, 1939.

The Hot Galvanising of Wire*

By a Special Contributor

Brief reference is made to the mechanism of corrosion of iron and steel wire, and to the general principles of hot galvanising. Old methods are referred to and present-day technique is discussed in detail. Particular attention is given to the equipment included in the layout of a modern plant for dealing with heavy- and thin-coated wire.

The wire should dip just under the surface of the zinc, for it is here that the metal is most pure and free from dross. The temperature of the pot must be pyrometrically controlled by a two-point recorder with couples at each end of the pot. If the pot is gas-fired, or electric-fired, the heating can be automatically controlled from the recorders.

The wire must attain the temperature of the bath—if it does not, the wire will come up rough. On the other hand, if left in too long, excessive dross is produced and output reduced.

For every gauge and quality of wire there is a definite speed and temperature for galvanising. Thick wires should be galvanised at a temperature of approximately 430° C., whilst thin wires require a higher temperature of about 460–470° C. The temperature increases as the diameter decreases, and vice versa, but at the same time there are several other factors which are involved. There is the tensile strength of the wire, depending upon the speed, length, and temperature of the tubing furnace, the efficiency of the cleaning, washing, fluxing, etc., depending upon the lengths of the respective tanks, and the speed of the wire, and in addition, the length of immersion in the spelter, the efficiency of the wiping and the cooling of the wire after galvanising.

The solvent action of zinc on iron increases slowly up to a critical temperature of 480°–490° C., after which it increases rapidly. At 500° C. it is ten times as fast, and at 530° C. it is thirty times as fast as the rate of attack below the critical temperature. Hence, this temperature of 480°–490° C. must never be exceeded, even locally, near the burners, etc., on the bath sides. At higher temperatures the metal is " burnt " and excessive zinc oxide produced. In addition, the $FeZn_7$ produced by the attack of the zinc on the bath sides protects them to a certain extent, and further attack can only proceed by diffusion. This becomes slower as the thickness of the $FeZn_7$ layer increases, but above the critical temperature this protective layer becomes porous and non-adhesive and falls away, exposing fresh surface to attack. Besides bad galvanising, this results in short bath life. Also, constant heating and cooling of the bath will cause this brittle layer to be broken and fall away, again resulting in short bath life.

The Wiping Bed.—This consists essentially of charcoal, either moistened with water or mixed intimately with tallow or heavy oil. A depth of about 6 in. of prepared charcoal is superimposed on 4 in. of dry charcoal. The degree of coarseness of the charcoal particles is important, and should just pass a 30-in. mesh. There should be no dust present. Whichever wipe is used, it must be maintained in its initial condition of humidity or oil content throughout the week, and this necessitates constant attention. The wire should leave the spelter vertically and immediately pass through the wiping bed resting on the surface of the spelter. If the wire leaves the spelter on the slant the molten zinc sets eccentrically on the wire, the thick part being on the underside. The more vertically the wire leaves the bath the more uniform is the thickness of the coat.

After leaving the wiping bed the wire should be cooled by quenching in a " Scotch Mist," generated by special water sprays. This accelerated cooling prevents undue oxidation of the zinc coating and so ensures a bright and silvery finish. Finally, the wire goes over the top pulleys situated well above the bath, and so to the winding blocks.

The Winding Frame.—Corresponding to the number of wires being galvanised, the winding frame consists of guide pulleys and winding blocks arranged on each side of the frame. Each wire is attached to its respective block, and as the block revolves, the wire is unwound from its swift, subjected to annealing, cleaning, washing, fluxing and galvanising, and finally wound up again into a coil of galvanised wire. The diameter of this coil is governed by the diameter of the block. The winding frame is fitted with a variable speed motor, so that a full range of speeds can be obtained for the different wires to be galvanised. Each block is independently controlled by a clutch attachment.

General Considerations.—All porcelain or earthenware rollers in the acid, washing and fluxing tanks should be well grooved to accommodate and separate all the wires ; they should be well balanced, and all of the same size and diameter, so that they can be interchanged if necessary. All rollers should have ball or roller bearings, so that the rollers are capable of revolving with a minimum of friction. The wire is severely tensioned, cold-worked, and hardened by variations in the diameter at the base of the grooves in the rollers and by acute and repeated bending of the wire.

Thin-coated or Wiped Galvanised Wire

In pressure wiping or " bobbin " wiping for thin-coated galvanised wires, the layout of the plant is very similar to that employed for heavy-coated wires. The only essential difference is in the wiping of the wire as it leaves the spelter and its treatment immediately after wiping. The wire leaves the spelter pot vertically, horizontally, or on the slant, and passes through a metal comb in the case of " bobbin " wiping, or a press in the case of pressure wiping. In the former method of wiping, asbestos strand is interwoven with several fine annealed wires, moistened in water, and allowed to thoroughly dry. This is then wrapped tightly and fastened round the wire before it enters the spelter. The wire pulls the wiper through the pot and is arrested in the comb on emerging at the other end, and as the teeth of the comb are wedge-shaped, the tendency is for the wiper to be compressed into the comb and become more effective in its wiping. Some are of the opinion that the asbestos fibre tends to give the galvanised wire a slightly grey cast, and so they dispense with the asbestos and simply use several lengths of fine annealed wire twisted together and tightly fastened round the wire. The pressure method of wiping between asbestos blocks or pads is the most effective wipe of all. In this method the wire passes between two asbestos pads tightly pressed together in a press actuated by a capstan screw. In all methods of wiping, the wiped wire must be instantly quenched in a cold stream of running water or dipped into a cold water tank to minimise oxidation and produce the micro-crystalline structure in the coating which is so essential for good coiling and bending and to produce a smooth silvery surface. One precaution which must be taken, however, is to have the zinc at an approximate temperature of 470° C. and to wipe the wire as close to the surface of the zinc as possible—2–3 in. at the most—otherwise the superfluous metal on the wire chills before reaching the wiper, producing rough wire. When the " hook and

*Continued from page 80, January issue.

eye " reaches the wiper, pull the wire out of the comb or press, fasten another wiper on, and make a fresh start.

Speeds employed in wiping plants are generally faster than those employed in heavy coated wires, so that greater care has to be taken in making sure that the wire is clean before going to the galvanising pot. This is sometimes overcome by cleaning the wire before putting it on the swifts, which in this case are submerged in water or very dilute sodium carbonate to prevent rusting. On account of the faster speeds employed in galvanised wiping plants, full annealing is difficult to obtain by passing through a tube furnace, and so in many wiping plants this is left out, and soft wire, when required, is pot annealed and cleaned in separate departments. Bright-drawn, low, medium and high tensile wires are cleaned first in boiling caustic solution and then in acid before being put on the swifts.

Theory of Fluxing and Galvanising

Little has been said about the action of the flux in galvanising, but the quality and judicious use of the flux is of paramount importance. Zinc chloride, ammonium chloride, or zinc ammonium chloride can be employed as fluxes in unalloyed zinc baths, but do not use ammonium chloride if the bath is alloyed with aluminium. The action of the flux is to unite with the film of metallic oxide on the wire at the temperature of the molten zinc, the impurities from which settle out as a streak along the surface of the molten spelter. A dirty wire is always indicated by a long streak, a clean wire by a short streak. A trace of glycerine is a useful addition, as it makes the flux viscous and frothy—the increased surface tension at the plane of contact drawing the impurities off the wire in a manner very similar to a soapy lather.

Even a practical article in galvanising must include a certain amount of theory, and so a brief account will be given of the bonding of zinc to iron and the factors governing it. During the immersion of iron and steel wire through molten spelter an alloy of zinc and iron, or rather a combination of iron-zinc alloys, is produced on the wire. The same thing applies to the bath itself containing the molten zinc and rollers, sinkers, roller bearings, drossing shovels, rakes, etc., which come into contact with the zinc. The amount of alloy produced and the speed at which it is produced is a time-temperature factor, and even if the wire is only in $\frac{1}{20}$ second, a certain amount of alloy is produced. The longer the time of immersion and the higher the temperature, the greater is the deposit of alloy. Excess of this alloy which cannot adhere to the work gradually settles at the bottom of the bath, forming an accumulation of dross. This dross is increased by the iron salts left on the wire through improper cleaning and boiling dross, and periodically must be removed, as it tends to foul the work being galvanised. The zinc-iron alloys produced on the wire are Fe_5Zn, Fe_3Zn, $FeZn_3$, and $FeZn_7$; the Fe_5Zn alloy containing 81% iron and the $FeZn_7$ 11% iron. These alloys are bonded on to the wire in the order given, the alloy richest in iron being immediately in contact with the base metal. The pulpy sediment of dross which settles down at the bottom of the bath, due to its relatively greater density and higher melting point, has a sugary consistency when molten. Solid dross has a denser, closer-grained fracture than pure zinc, and a comparatively dark greyish appearance with black spots of iron crystallites. As it contains only 3–4% Fe, the rest being 96–97% Zn, it can be readily appreciated what a considerable bulk of zinc a slight amount of iron will contaminate. Because of its contamination of pure zinc " dross will make dross," and it is essential to keep the dross content of the bath down to a minimum. The final layer on the wire approximates in composition to the composition of the bath, but sometimes it contains inclusions and crystallites of iron. The banded structure of hot galvanised wire can be distinctly seen when a prepared section is examined under a microscope. Unfortunately, iron embrittles zinc and the zinc-iron alloys produced will readily crack and flake, forcing the comparatively ductile zinc coating away. Therefore it is essential to keep the alloy bond between the zinc coating and the iron base, in hot galvanising, as thin as possible. The alloy layers should also be smooth and uniform in thickness (not " tree-like " in appearance) for good bending and coiling properties, as the greatest adhesion of the zinc to the base metal results from an even contour. Good bending is effected in practice by :—

1. Employing as low a galvanising temperature as possible.

2. Employing as short an immersion as possible—the instant the wire has attained the bath temperature it is ready for withdrawal.

3. Top-firing to minimise " floatation " of dross—equilibrium exists between the three factors, zinc, dross, iron-work and wire, and the Fe in solid solution in the wire coating. The less the dross the less the iron in solution in the Zn, and so the better the work produced. Incidentally, Fe rich spelter baths necessitate the use of increased temperatures, to maintain the necessary degree of fluidity.

4. Rapid quenching of the galvanised wire to prevent continuation of the alloy action.

Thorough cleansing of the work free of iron salts, use of neutral fluxes, and use of alloy additions, have a great bearing on the thickness and nature of the bond. The alloys used are zinc and aluminium or Bright Metal (Zn 87·10, Al 11·14, Pb 0·465, Sn 0·804) and zinc and tin, or Silver Metal (Zn 89·10, Al 2·45, Pb 0·40, Sn 7·61), both with a melting-point approximating to 440° C. Aluminium not only increases the fluidity of the bath and so precipitates the iron and lead held in solid solution, but also slows down the reaction rates between the zinc and the iron, thus materially decreasing the amount of brittle bond produced. Tin increases the fluidity of zinc by its de-oxidising action. In both cases this fluidity of the bath allows the galvanising temperature to be proportionately lowered. Aluminium and tin, however, are most usually employed in wiping plants to produce a better colour and finish on the wiped galvanised wire.

New Standard Test for Galvanised Wire

A BRITISH Standard Specification for the Testing of the Zinc Coating on Galvanised Wires was issued in 1932. The method employed was the copper sulphate dipping test, but it was at that time appreciated by the British Standards Institution Committee that the copper sulphate test left much to be desired as a real criterion of the quality of the galvanising.

During the last few years considerable research work has been carried out in many countries, and this is reflected in a new edition of British Standard Specification No. 443, which has just been published. The principal feature of this new edition is the introduction of a test for the minimum weights of zinc per unit area on zinc-coated wires. This test has been introduced in substitution for the copper sulphate test on straight wires, but the latter test is retained for testing wires after being wrapped and unwrapped round a mandrel of specified diameter. Any advantages which the copper sulphate test may possess, such as an indication of the uniformity and concentricity of the coat, are therefore not lost in the new specification, but the specification itself is strengthened by the definition of the minimum weight of coat which the wire itself should carry.

The method of determining the weight of coat is the same as that recommended by the American Society for Testing Materials, the wire being stripped of the zinc coating by immersion in a solution of antimony chloride and hydrochloric acid. The minimum weight of coat is graded according to the diameter of the wire, and is expressed in ounces per square foot and in g. per metre.

Copies of this Specification (B.S. 443-1939) may be obtained from the British Standards Institution (Publications Department), 28, Victoria Street, London, S.W. 1, price 2s. 2d. post free.

Refractory Materials for Reverberatory Furnaces

By Alfred B. Searle.

The seven essential parts of the reverberatory furnaces are discussed with respect to refractory materials, in the fireplace, bridge, hearth, nozzles, side walls, roof, and the flue. Emphasis is laid on the importance of careful selection for the particular part of a furnace to ensure economical service.

IN selecting bricks for reverberatory furnaces, it is essential to have a fairly clear idea of the distribution of the heat, as otherwise, money may be wasted by using needlessly costly bricks where cheaper ones will do, or some of the bricks may fail prematurely because they are not suitable for those parts of the furnace in which they are used. Broadly speaking, a reverberatory furnace may be compared to an inverted river bed, the flames and hot gases corresponding to the water. They enter at one end of the furnace, flow through it, mainly in a horizontal direction, and then into the flue leading to the chimney. It is a common, yet serious, error, to suppose that the flames and hot gases uniformly fill the furnace, because they do not ; the hotter and, therefore, lighter gases tend to rise and to travel along the upper part of the furnace and flue, and the cooler, denser gases tend to pass along the lower parts. As the flames are denser than the hottest gas they tend to travel intermediately, but their direction is also affected by their being reflected from the arch and walls of the furnace. If the latter is properly designed a large part of the contents of the furnace will be licked by the flames. Instead, therefore, of the usual conception of a steady flow of flames and hot gases, what actually occurs is a series of streams which are mainly horizontal but which are traversed at frequent intervals by ascending and descending streams, the parts of the furnace which cause a change in the directions of these streams being those most seriously affected thereby. The existence of these numerous transverse streams largely accounts for the excessive wear and tear in patches which is so common a feature in reverberatory furnaces—a cause which, curiously enough, has been largely overlooked by furnace builders and users.

The chief property which refractory materials used in reverberatory furnaces must possess is that of remaining undamaged by the rapid changes in temperature to which they are subjected. Other properties which are also of great importance include resistance to slags and flue-dust, ample mechanical strength, impermeability to any corrosive substances which may be present, and resistance to furnace gases.

The design of a reverberatory furnace has a great influence on the durability of the refractory materials used in its construction. Consequently, sound foundations of ample size are essential.

A reverberatory furnace has seven essential parts : (i) the fireplace, which contains the fuel and in which the heat is produced ; (ii) the bridge, over which the flames and hot gases pass into the furnace proper, the space above the bridge also acting as a combustion chamber in which air is mixed with the hot gases ; (iii) the hearth, on which the material to be heated is placed ; (iv) the nozzles, through which molten slag and other molten material (such as metal or glass) may be discharged from the furnace, larger openings fitted with brickwork doors being provided when the contents of the furnace are withdrawn in the solid state ; (v) the side walls ; (vi) the arch or roof of the furnace, which, in turn, may be regarded as in four parts—namely, that over the fireplace, that over the bridge, that over the hearth, and, in many furnaces, that forming the top of the flue ; (vii) the flue leading to the chimney.

The size, shape and relative position of each of these parts of the furnace has an important effect on its working and an equally pronounced influence on the durability of the refractory bricks used in various parts of the furnace. For instance, if the mouth of the flue is too high, the hot gases and flames will tend to travel above the hearth, and unless an appreciable pressure is maintained in the furnace it will be difficult to heat the contents sufficiently. Even if sufficient pressure can be maintained it will involve a serious waste of fuel, and unless special care is taken in selecting the bricks they will not prove sufficiently durable. Similarly, too small or too large a space above the bridge will also cause excessive wear of the bricks in quite a different part of the furnace, and unless the user really understands what is occurring it may be difficult to find the true cause of the defect.

The Fireplace

Taking each of these parts in turn, the bricks of which they are constructed should be chosen to meet the particular requirements of each part. Thus, although the heat is produced in the fireplace, it is seldom that this is the hottest part of the furnace ; on the contrary, much of the brickwork in the fireplace never attains a bright red heat. It is only the arch and the upper parts of the walls which become really hot, and in some furnaces even these parts do not attain a temperature above 1,500° C. The chief cause of destruction of the brickwork in the fireplace is not the high temperature attained, but the corrosive action of the ash and clinker and the abrasive action of the fuel and clinker and of the tools used by the fireman. Hence, strength and toughness rather than great refractoriness are needed in the bricks used in this part of the furnace. Ordinary firebricks of good quality, accurate in shape and with a fairly dense surface, but a porous interior, are quite suitable ; special bricks are seldom needed.

The Bridge

For the bridge which separates the fireplace from the hearth a different quality of brick is needed, for the bridge is subject to an incessant bombardment by flames and hot gases carrying flue-dust in suspension. The flames are often reducing in nature and the flue-dust is violently corrosive as well as abrasive, so that hard and tough bricks are required with a fairly high refractoriness. The most serious destruction occurs in the top two courses, so that whilst cheaper bricks may be used for the lower ones, the upper courses should be made of dense, well-burned fireclay bricks containing at least 30% of alumina. This will enable them to resist chemical corrosion, because the alumino-silicates are more viscous and most of them melt at a higher temperature than the silicates devoid of alumina. The bricks should be burned as hard as possible (no attention being paid to their colour and spottiness) as this will give them a greater resistance to the scouring action of the flames and dust.

The bridge should be built wholly of headers and stepped back from the firegrate so as to reduce its liability to burn away.

The flame-way or space over the bridge should be of ample size or excessive corrosion of the brickwork above it will occur. A suitable area for the flame-way is half that

of the hearth, but in each furnace it should be modified, as required.

The Hearth

The hearth should be built of bricks chosen on account of their resistance to the chemical action of the metal, slag and other contents of the furnace. They should be refractory, but not necessarily of the highest refractoriness as the hearth is seldom the hottest part of the furnace. They should be as accurate as possible in shape so as to be laid with the thinnest possible joints; if the joints are wide or open when the furnace is in use, some of the contents of the furnace may penetrate between the bricks and be lost. In an extreme case, sufficient molten material may pass through the joints to cause some of the bricks in the hearth to rise out of place and even to float on the molten contents. Fireclay bricks, unless very well burned, tend to shrink in use, so that it is customary to use silica bricks, which tend to expand on heating, for some furnace-hearths. If, however, the fireclay or semi-silica bricks have been properly burned, they often produce a more impermeable hearth than silica bricks. In many metallurgical furnaces, the hearth is covered with ground ganister or with a mixture of white sand and clay, carefully rammed and superfused before charging the furnace. Such a covering is easily repaired and greatly reduces the loss of metal by percolation.

Many substitutes have been tried, two of which need only be mentioned here—namely, clay chrome, and magnesite bricks. The success of these latter bricks has been very limited, and they have had comparatively little application up to the present time. Silica is usually fritted into the bottom to form a single block, and is the commonest material for a working bottom. The depth of this bottom varies from about 2–3 ft.

As is well known, the specific gravity of quartz and tridymite differs, the former being 2·65 and the latter 2·32. On heating, quartz is slowly converted to tridymite with a corresponding increase of volume (about 20%). Silica sand which is most desirable is that which contains the most tridymite or original quartz which has been converted into tridymite by calcining. The more finely divided the particles of the constituents—*i.e.*, silica, ferric oxide, lime, alumina, the more easily will the quartz be converted to tridymite. The hearth will also be stronger, on account of the uniform distribution of the bond, which holds the particles of silica together. Some sands contain sufficient bases to be slightly fusible, and adhere firmly to the brick bed without the need for further additions. In other instances, a small proportion of crushed slag is mixed with the sand prior to working it into the hearth. Sometimes the sand is fritted in the furnace, and molten slag poured on top to fill in the interstices and bind the particles together.

When sand and an admixture of slag is employed, the mixture is moistened and rammed down firmly, hand rammers or flat-headed hammers being used. It is customary to keep these rammers heated on a coke fire when not required, and only used when hot. After the desired shape has been formed, the furnace is warmed gradually to drive off all moisture, and then uniformly raised to the highest possible degree of temperature. This degree is maintained until the bottom has sintered to some depth, when it is soaked by the addition of a little slag.

Where the temperatures reached are higher than usual, the mixture rammed consists of fireclay and chrome iron ore, but this is only used in special cases. Beneath the lining a course of red brick is laid, and below that the foundation is formed of concrete. The bottom is supposed to be non-absorbent and capable of resisting corrosion. In some works, the sand and slag are spread in thin layers, each being separately sintered before adding the succeeding mixture, after which sand is paddled or moulded in as required by means of a long-handled instrument.

Where clay is used, a layer of several inches is spread on the top of the brickwork to prevent any percolation of molten metal. A fire is kindled on the clay bed and raised gradually until the clay assumes a dark red colour, when it is understood to be free from all moisture and organic matter. Sand is then charged and calcined to convert quartz in part to tridymite, the mass being rabbled backward and forward for some time. It is then formed into shape and sintered at a high temperature, as before.

When the bottom is to be built of silica bricks a sand bottom is first rammed into the form of an inverted arch. On top of this the silica bricks are laid, the number of courses depending on the size of the furnace built. To provide room for expansion, cardboard is placed between the bricks every few feet. Where the heat is greatest, that is at the firing end, silica bricks and cardboard are laid alternately.

In furnaces intended to work at high temperatures, the hearth should slope gradually towards the flue, in order to allow the molten slag, formed by the union of the silica of the hearth with the scale of oxide of iron from the charge, to flow into the bottom of the flue, near the chimney, from whence it may run through a cast-iron or cast-steel slag spout into portable slag boxes or trolleys. The internal height of the hearth, whilst essentially governed by the size and nature of the charge, should be kept to a minimum; considerable disadvantage and waste of fuel results from unnecessarily large internal heights.

To prevent the possibility of part of the hearth floating up, due to the molten metal breaking through, the structure should be well keyed and grouted.

The nozzles or outlets are usually made of fireclay blocks made for the purpose and are fitted with stoppers made of the same material; the fireclay should be of good quality, but the most refractory material is seldom used. Other substances, such as dead-burned magnesite, are sometimes more durable, but are much more costly.

The Side Walls

The side walls of a reverberatory furnace call for special care in selection, as they must possess sufficient resistance to withstand any stresses to which they are likely to be subjected and particularly to the thrust of the arch ore roof. The walls are usually built of two kinds of bricks, red engineering bricks being employed for the outside and to provide the requisite strength, whilst firebricks, whose chief purpose is to retain the heat in the furnace and to provide a surface which will not be damaged by the contents of the furnace, are employed for the inside. A considerable saving in heat will be effected if a course of insulating bricks is built between the outer and inner bricks forming the walls of the furnace.

The lower part—*i.e.*, that below the slag line—does not usually wear away very rapidly, but the courses of brickwork in contact with the slag sometimes last only a very short period and, owing to their position, they are difficult to replace. Such bricks should be dense, high in alumina, and well burned, so as to resist the corrosive and chemical action of the slag as much as possible. Some of the bricks in the upper parts of the walls may also wear away as the result of splashes of slag, but in most reverberatory furnaces the bricks in the upper parts of the walls need not be specially resistant to corrosion, though they should be refractory and fairly dense in texture; they may be made of either fireclay or silica, the former being preferable when the changes in the temperature of the furnace are very great or where the slag is highly corrosive.

The Roof

The arch is, in some respects, the most difficult part of a reverberatory furnace so far as the choice of bricks is concerned, for it is subjected to the most intense heat, to sudden currents of nearly cold air, to violent splashes of slag, and to the corrosive action of the flue-dust, and of the flames. Under such conditions, it is somewhat remarkable that arches last as long as they do, and their durability is a striking testimonial to the suitability of the bricks employed.

The arch which forms the top of the furnace should be of such a shape that it tends to deflect any gases which come into contact with it and to return them to the hearth and not to the sides of the furnace. This directional reflection is best achieved by making the curve of the arch a part of a true semi-circle and not of any other curve. The arch is best made of silica bricks, though these will spall if the furnace is worked carelessly so that a rush of cold air enters the furnace and "checks" the hot brickwork causing cracks and spalling.

For many furnace arches, silica bricks are preferred to those made of fireclay on account of the tendency of the former to expand when heated, whereas the latter tend to contract and so cause the arch to collapse. Semi-silica bricks are constant in volume and possess many of the advantages (and some of the drawbacks) of the two other kinds.

The bricks used for the portion of the arch which is above the fireplace will be liable to the most severe abrasion and corrosion, but as in some reverberatory furnaces the maximum heat in the flame is not developed in that part, the bricks used for that portion of the arch need not have the highest refractoriness; this is a matter which depends on the design of the furnace and can only be considered satisfactorily in connection with each individual structure.

The bricks used in the part of the furnace immediately over the bridge and over the front of the hearth are usually the ones exposed to the most severe conditions as not only do the flames and hot gases pass at a rapid rate (which results in additional abrasion), but the highest temperature is often attained at this point so that bricks of great refractoriness are needed. Unfortunately, it is extremely difficult to obtain bricks which are highly refractory and yet are sufficiently hard and dense to resist abrasion and chemical corrosion, but wherever possible, such bricks should be used in this part of the arch.

For the portion of the arch immediately above the hearth great refractoriness is one of the chief requisites, though a dense, smooth surface to which splashes of slag will not cling is a great advantage and adds considerably to the durability of the arch. The bricks should also be well burned and hard as they rub against each other during the expansion and contraction of the arch, and unless very strong will tend to crumble away. The joints should be as thin as possible.

The Flue

The bricks used in the flue need not be so refractory as those in the arch, though it is a wise precaution to use similar bricks for the first few feet of the flue. The entrance to the flue is particularly liable to be worn away and should be made of the hardest refractory bricks, the others need not be so refractory, but must be hard as they have to withstand a rapid current of hot gases heavily charged with dust of a highly abrasive and corrosive character. To reduce the damage, some firms build a smoke chamber immediately behind the back wall of the furnace in which the greater part of the dust can settle before the gases enter the flue; this is of considerable benefit. As the temperature in the flue diminishes rapidly, bricks of comparatively low refractoriness may be used for the greater part of it, though it is not advisable to go to too great an extreme in this respect.

If the entrance of the flue has an area less than one-tenth of that of the firegrate the furnace may be difficult to work and the bricks at the entrance to the flue may perish quickly. An excessively large flue should be avoided as it wastes fuel.

Excessive destruction of the bricks forming the flue is sometimes due to too sharp an angle in the flue.

When it is necessary to deviate the direction of the flue, this should be accomplished by an easy curve in the flue of as large a radius as practicable.

The flue should be "bottomed" with sand, especially near the slag channel. The walls should be 4½ in., all stretchers, or, preferably, 9 in., all headers.

Reverberatory furnaces are sometimes constructed to work on the regenerative principle. This is usually accomplished by building the roof, and back and grate-end walls double, with a continuous 9-in. air passage between. A fuel economy is thus effected, as the air, entering between the double roof and passing between the double walls, becomes highly heated before reaching the fire-grate.

The chimney stack usually varies in height from 35–50 ft. The area of the chimney should generally vary between one-fifth and one-quarter the area of the firegrate. It is usually built square, lined with 4½ in. of firebrick, and is well braced together by wrought-iron flats. If built square, the length of each side should, in ordinary practice, be a multiple or half multiple of the length of one brick, so as to obviate the necessity for cutting and chipping the bricks when building and repairing.

All new brickwork should be carefully yet thoroughly dried before the furnace is used, as nothing damages refractory brickwork more than a sudden heating of the damp material.

Water-cooled walls are used in some reverberatory furnaces and have proved satisfactory so far as durability is concerned, but are wasteful in fuel. Special care must be taken to prevent any water entering the furnace, and, consequently, steel plates are largely used for water cooling, the refractory material being laid in contact with these plates. There is little advantage in using a highly refractory material in a water-cooled wall, so that fireclay bricks are generally employed for this purpose.

To conclude, each part of a reverberatory furnace should be built of bricks specially suitable for that part. By this means, the advantages of each type of brick will be realised, yet no needless expense will be incurred by the use of costly bricks where they are not needed. There is much room for improvement in arranging the detailed measurements of many reverberatory furnaces, and if these are incorrect the furnace will be out of proportion. This may not prevent it doing its work, but it will probably involve undue strain on some portion of the brickwork and will, therefore, reduce the durability of it as well as increase the fuel consumption. Moreover, such a defect often leads to good bricks being condemned as unsatisfactory when the essential fault is in some detail of the dimensions of the furnace. No reverberatory furnace is so simple in action as it appears to be at first sight, and if the brickwork used in its construction is to be chosen satisfactorily, the selection must be detailed and should be made with a full cognisance of the particular conditions the bricks are expected to endure. As these differ in each part of the furnace, no general order for "best firebricks" or "best silica bricks" can be wholly satisfactory.

Revised and New Specifications

Round Strand Steel Wire Ropes for Lifts and Hoists

THE British Standards Institution has just issued the Revision of B.S. 329, Round Strand Steel Wire Ropes for Lifts and Hoists.

The revised specification provides for round strand ropes of Lang's or Ordinary Lay of 6 × 12 and fibre, 6 × 19, 6 × 19 Seale and 6 × 24 constructions, for use with cage or platform hoists or lifts (for passengers or goods) working in guides. It is not intended to apply to ropes for coal hoists or similar lifting appliances.

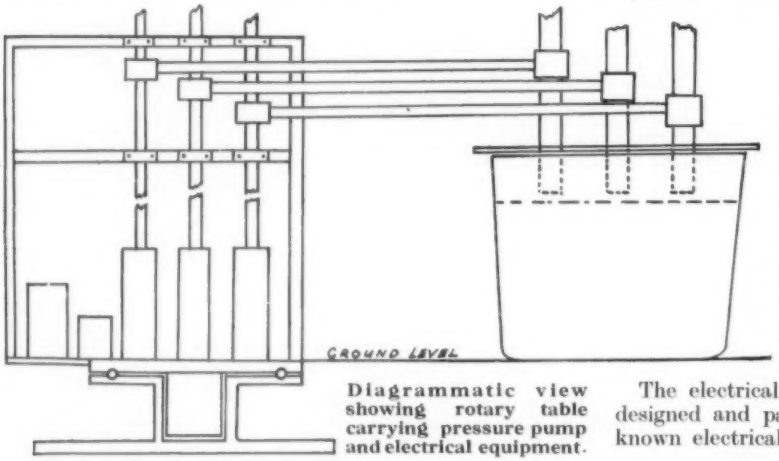
In the revised specification wire below 80–90 tons per sq. in. has been eliminated, and bend tests on the wires have been included in addition to the torsion tests, and the sizes of ropes are now limited to ropes from ¾ in. to 1¾ in. circumference.

The foreword of the specification has been considerably amplified, and modifications have been made to the recommended sizes of drums, sheaves and diverter pulleys.

Temperature Control and Superheating for Cast Iron

(CAMPBELL SYSTEM.)

THIS system has been evolved to facilitate and assist iron foundry work in particular. It is primarily intended for maintaining the temperature of the iron or to superheat in the ladle, and with that object practical electrical equipment has been designed. The equipment includes three electrodes, which are mounted, with the usual connections, from arms operated by hydraulic pressure for the rise and fall. The pressure pump, also the overflow tank, and the whole of the electrical equipment is contained on a rotating table, which is at floor level—the base being under floor level, as shown on the following diagrammatical sketch. The electrodes are enabled to rotate on the sunken base in practically a full circle. In a busy foundry, it is usual to arrange the casting and the preparation of the moulds to coincide with reasonable time limits. This is not always practicable, and at times the melting is slowed up, a practice not looked upon favourably by the cupola operators. The adaptability of the electrical system avoids this, and has some important metallurgical advantages readily appreciated by metallurgists, and by practical foundrymen—it enables speedier and continuous operation of the cupolas.



Diagrammatic view showing rotary table carrying pressure pump and electrical equipment.

The electrodes may be operated upon several ladles containing 2 tons and upwards of iron. Samples may be taken for fracture, and suitable alloy additions may be made, if necessary, the whole superheated and complete solubility and structure control obtained. It further enables the moulding departments to commence casting when all their preparations have been made. Hold up of melting is obviated, and particularly the checking of temperature and of obtaining consistently correct iron for any particular group of castings.

A suitable bay, enabling the ladles to be contained within the radius of the electrodes, will deal with several ladles. The electrodes are lowered through a light and removable refractory cover placed on the top of each ladle, and approximately 15 mins. is sufficient to superheat, if necessary, or after alloy additions—this depending upon the initial temperature of the iron, the alloy additions, and the length of time before casting

The total carbon contents may be too high in cupola practice, even with the addition of steel scrap, commonly used. This may be considerably lowered by the addition of steel scrap to the ladle, and the temperature raised, also additions, such as silicon, nickel and chromium may be made after weighing the iron and calculating the exact quality required for physical test and structure control. This system is not intended to supersede, or attempt reduction and refining, which is primarily the operation on a suitable electric hearth. It is, however, a practical method of retaining the temperature in the ladles, or of superheating either with or without alloy additions. It also allows time to take fracture tests and to adjust, if necessary, and to produce suitable controlled qualities as and when required. It would, therefore, solve some of the difficulties encountered in everyday foundry practice and also facilitate production.

It appears that the cost of this heating unit adds itself to the basis cost of the cupola iron finally ready to pour. Such may not be the case, as cheaper charges may be used in the way of scrap iron or steel—the adjustment in structure analysis can then be obtained by ladle additions. The additions melted actually in the cupola are not the same.

Inoculation can only be obtained by additions to the molten cupola metal in the ladle, which is undoubtedly improved by raising the initial temperature. Assuming the initial temperature is 1450° C., the additions added and the temperature raised to 1600° C., the superheating and duration of this treatment influences the complete solution of the carbon. When additions are not required, or when suitable charges were made in the cupola, the raising of the cupola iron temperature has a refining tendency, with improved physical results, together with higher casting production. There is a slight reduction in carbon and silicon, but the transverse strength may be increased from an actual test record—from 3,700 lb. to 5,100 lb. The Brinell hardness is raised, and machining operations are improved.

It may be stated that superheating will obviate the use of special pig iron. It may be considered essential for revivification when using a large amount of scrap. Exceptional strength and similar properties associated with high duty iron can be produced with practically all scrap charges, if additions are made for structure control—and superheating. An example of the extra cost for current consumption is under 4s. per ton. This cost can easily be recovered on the cheaper cupola charge, excluding coke charges—usually increased with large scrap additions,—with a consequent reduction of sulphur.

The electrical equipment for this system is especially designed and patented, and is manufactured by a well-known electrical company.

Steel Tubes for Water Well Casing

AT the request of the War Office, and with the full co-operation of the Waterwell Drillers' Association, the British Standards Institution has recently issued a British Standard for Steel Tubes for Water Well Casing (B.S. 879-1939).

The specification applies to lapwelded and weldless tubes of nominal diameters from 4 in. to 48 in., with two types of screwed joints—namely, screwed and socketed (with V or square form threads) and with flush joints inside and out with square-form threads.

The quality of the steel is determined by tensile bend and flattening tests, while flattening tests are also included to determine the quality of the weld. Hydraulic test pressures are prescribed, and general requirements are included in respect of the accuracy of the alignment of joints, of coating and oiling of tubes, and of packing for transport.

Fully detailed requirements are given for the dimensions of the tubes and sockets and their screw threads.

Copies of each of these Specifications may be had from the British Standards Institution, 28, Victoria Street, London, S.W. 1, price 2s., 2s. 2d. post free.

Dr. H. W. Brownsdon has retired from I.C.I. Metals, Ltd., and has felt it his duty also to retire from taking an active part in the work of the British Non-Ferrous Metals Research Association.

Copper-Zirconium-Cadmium Bronze

An investigation of copper-zirconium-cadmium alloys is discussed, the results of which indicate a new high-strength, high-conductivity alloy has been produced which constitutes a substantial improvement in hardness and strength over present copper-cadmium bronzes without causing a severe loss in electrical conductivity.

IN re-investigating part of the binary system of copper and zirconium, and comparing the results obtained with other commercial available materials, Hensel, Larsen, and Doty concluded that the properties of these alloys and more particularly the hardness, did not make the material suitable as a substitute for present-day alloys. In order, therefore, to obtain a new commercial alloy of high electrical and tensile properties, the ternary system copper-cadmium-zirconium was investigated in the range, where such alloys can be hot- and cold-worked, and treated in such a manner as to develop the best combination of electrical conductivity and tensile properties. The spectical composition of the most suitable alloy was established at 0·35% zirconium, 0·90% cadmium, balance copper.

In preparing this bronze it was found that the addition of pure zirconium to copper was highly impractical from the standpoint of zirconium recovery and formation of zirconium oxide. It was found necessary to prepare hardeners by a powder metallurgical process containing 12·5% and 35% zirconium, respectively. Cadmium was added in the form of compressed copper-cadmium briquettes containing 25% cadmium. The copper was melted under a charcoal cover, a small amount of copper-phosphorus added, then the zirconium hardener, and finally the cadmium hardener. The alloy was cast into chilled moulds at 1150° C., 10 min. after the addition of the zirconium hardener. Several large production heats of this copper-zirconium-cadmium bronze were also made, the materials being melted in a 60-cycle Ajax-Wyatt induction furnace.

Tests were carried out on the age-hardening properties and on the effect of combining cold work with ageing. Previous to making the age-hardening tests, a series of tests was conducted to determine the effect of deoxidisers such as phosphorus, silicon, magnesium and lithium on the age-hardening characteristics. Copper-zirconium-cadmium alloys were prepared containing 0·05% phosphorus, 0·06% magnesium, 0·09% silicon, and 0·03% lithium, respectively. It was definitely established that the presence of phosphorus seriously interfered with the age-hardening of the alloy. With magnesium the most pronounced hardening resulted by quenching at 900° C., and ageing for eight to 16 hours at 450° C. The best quenching temperature for silicon and lithium was 925° C., and the most pronounced ageing resulted at 450° C.

A series of cold-work tests was made on an alloy containing 98·97% copper, 0·28% zirconium, and 0·72% cadmium. When this alloy was quenched from temperatures varying from 800° to 1000° C. and cold-worked to various percentages, it was found that 45% cold work gave the maximum increase in hardness at all the quenching temperatures. To determine the effect of cold working after ageing, this alloy was quenched at temperatures varying from 800° to 1000° C., aged eight hours at 400° C., and cold-hammered to 15%, 30% and 45% reduction in thickness, when it was found that a 25 to 35% reduction after ageing raised the hardness considerably. It was therefore decided as a result of these tests that for processing commercial quantities of copper-zirconium bronze 40 to 50% of cold work is necessary after quenching, and 25 to 35% after quenching and ageing.

To obtain data regarding the hardness at various points in the process of treating copper-zirconium bronze, seven alloys were prepared containing 0·34 to 0·59% zirconium and 0·70 to 0·98% cadmium. These alloys were quenched from 850°, 875°, 900° and 925° C., cold work 40 to 50%, aged one and two hours at 400° C., and further cold worked to 25 to 50% reduction in thickness. The hardness (Rockwell B) varied from 65 to 74 after quenching and cold working, from 69 to 81 after ageing, and from 73 to 86 after ageing and cold-working. From the data obtained it was evident that, with the proper treatment, the new alloys can be produced with a minimum hardness of 80 Rockwell B, and an average hardness of 83 to 85 Rockwell B, in sections up to 1 in. diameter.

Production heats of the alloy were investigated as far as hardness and electrical conductivity were concerned, and tensile tests were made on round rods drawn to various dimensions. Average tensile and other properties are shown from tests made on a $\frac{5}{8}$-in.-diameter rod.

Ultimate strength (tons per sq. in.)	34·8
Yield point (tons per sq. in.)	32·6
Proportional limit (tons per sq. in.)	16·7
Elongation on 2 in.	11%
Reduction in area	40%
Hardness (Rockwell B)	84–86
Electrical conductivity	78%

The alloy also forged satisfactorily. It was found that extruded billets forged more readily than cast billets. A large number of forged rings and discs had hardnesses varying from 78 to 85. The softening characteristics of the alloy were determined by annealing the material for two hours at various temperatures when a drop in hardness was found to occur about 450° C. As softening is a function of the amount of cold work that is applied to the material, with a very high amount of cold work the material over ages rather quickly, and softening occurs as low as 400° C. Hardness tests made at elevated temperatures gave the following values :

Temperature (° C.).	Brinell Hardness.
15	148
125	140
175	132
230	123
300	120
350	119

It was found that copper-zirconium-cadmium alloys which had been quenched from too high a temperature after hot-forging would crack on subsequent cold-working. A microscopic examination showed that at certain temperatures considerable grain growth occurred accompanied by segration in the grain boundaries on prolonged heating, and indicated that the quenching temperature should not exceed 950° C., and should preferably be 900° C., and that the material should not be held for too long a period at such a high temperature.

In addition to the copper-zirconium-cadmium system, a number of other systems were also studied, such as the copper-zirconium-tin system, when it was found that zirconium also causes age hardening. Another system found to give excellent properties was the copper-zirconium-iron alloys. Materials of this type could be age-hardened without cold work to a Rockwell B hardness of 62 to 65 and an electrical conductivity of 55 to 60%. Further cold working raised the Rockwell B hardness to 85. It was also found that additions of zirconium greatly improved alloys hardened with chromium silicides and nickel silicides.

It appears, therefore, that the investigation of the copper-zirconium-cadmium alloys has produced a new high strength, high conductivity alloy, which constitutes a very

Metals and Alloys, 1939, Vol. 10, No. 12, pp. 372–380.

substantial improvement in hardness and strength over present copper-cadmium bronzes without causing a severe loss in electrical conductivity. This alloy can be manufactured very satisfactorily on a large scale, and can be handled in a mill without difficulties. It has been produced on a tonnage basis, and is being used for electrical conducting members, welding electrodes, and heat-conducting members. Such material should also form an excellent alloy for high strength, high-conductivity wire, such as is used for overhead wire and trolley wire.

The Structure and the Mechanical Properties of Special Cast Irons

Results are given of an investigation designed to determine the connection between variables in order to produce cast irons of certain properties regularly.

IT is well known that the structure, and especially the quantity and formation of the enclosed graphite, have great influence on the mechanical properties of cast iron. The development of highly valuable cast irons is based on this fact. An extensive literature shows how efforts were made to decrease the formation of graphite by diminishing the carbon contents; then to refine the graphite by overheating the cast, and recently to produce a white cast iron to which additions subsequently put into the ladle brought about the formation of graphite.

It was the purpose of the two authors of this publication, Peter Bardenhener and Wilhelm Bröhl, to present a new contribution to these investigations, and especially to find out the connection between the various variables, so that cast irons of certain properties could be produced systematically; but attention is drawn to the fact that the cast irons in question can be used only in special cases, as the improvement obtained by the methods described is connected with deficiencies in comparison to the usual grey cast iron—e.g., smaller capacity of casting, greater shrinkage, smaller damping capacity, etc.

The experiments have been carried out on specimens taken from 17 melts, the analyses of which were between the limits 1·53 to 3·06% carbon, 1·19 to 4·80% silicon, and 0·79 to 4·52% manganese. The melts have been made in a high-frequency furnace. Four rods of 1¼ in. diameter and 26 in. length have been cast of each melt, two into sand and two into chills, of which three have been heat-treated in different manner, while one cast into sand is kept as it was cast for comparison purposes. Bend, tensile, hardness, and notched-bar tests have been carried out on specimens of all rods, and investigations under the microscope have been made on etched as well as unetched test-pieces.

The results of the tests may be summarised as follows:—

1. The formation of graphite was influenced favourably, and the strength was increased while the carbon and silicon contents decreased. With very low carbon contents the formation of graphite became similar to temper carbon.

2. The increase of manganese contents of sand-cast specimens up to 1·2% of not heat-treated and up to 1·4% of heat-treated material resulted in an increase of tensile strength; but the strength decreased slightly when the manganese contents exceeded these figures. With chill-cast specimens the tensile strength decreased when the manganese contents increased.

3. The Brinell hardness increased with increasing manganese contents in all heat-treated specimens, but decreased in the specimens not heat-treated after reaching a maximum at 1·2% Mn. The maximum impact value was obtained at 1·4% Mn.

4. Casts with high contents up to 4·8% silicon and 4·5% manganese, and comparatively high-carbon contents decreased greatly in strength without regard to the manner of casting or heat-treatment; but with low-carbon contents the mechanical properties were very satisfactory. High-manganese contents reduced the workability.

5. Some melts have been treated separately in order to find out how far the number of nuclei of crystallisation and the rate of crystallisation, and especially the ability to be under-cooled can be influenced by simple methods: it could be proved that if a melt free of nuclei solidified, the apparent eutectic alloy seemed to depreciate very much the mechanical properties. By additions of soda and carbon establishing centres of crystallisation to a melt of low carbon content in the ladle, a structure of temper carbon and pearlite developed. The experiment of adding only soda to melts of higher carbon contents was not successful. Likewise, the use of calcium silicide with melts of high-silicon contents was only partly a success; the under-cooling could be prevented only with the sand-casts, but not with the chill-casts. It is tried to give an explanation of the nature of such efficient nuclei according to recent literature.

6. The temper carbon, the formation of graphite which is most favourable for the mechanical properties, could be obtained in white chill-casts by subsequent heat-treatment, but in grey-casts only with carbon contents of less than 2%. The mechanical properties could be improved by heat-treatment; annealing was useful in the case of medium carbon contents, but with low carbon oil-quenching with subsequent annealing at high temperature was necessary.

Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung in Düsseldorf. Vol. 20, No. 11.

The Forging of Aluminium Alloys

(*Continued from page* 116)

secondary requirements are: (1) Easy machining; (2) strength at elevated temperatures; (3) adaptability to various finishing operations.

No aluminium alloy complies with all these requirements, and this explains why at present the five various types of aluminium alloys or their derivatives are still in use for the production of forgings.

The importance of fibre flow is even greater in aluminium alloys than in other metals, and special attention should be given to this factor in preparing the die design and checking the flow of the fibre on trial forgings. The adoption of the upsetting machine in the production of some aluminium alloy forgings is mainly due to the necessity of achieving the best fibre flow.

The present forging equipment for aluminium alloys compares already in size with that used for steel, and this illustrates how far the forging technique for aluminium alloys has been developed within the past two decades only.

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METALLURGIA. Contents. For FEBRUARY, 1940.

	Page
A Note on the Absorption of Graphite in Hardening and Tempering Cast Iron. By Dr. J. E. Hurst *Results of investigations are given which demonstrate the quench-hardening effect in specimens of cast iron, in spite of the absence of combined carbon.*	91–94
The Constructural Changes in Copper Effected by Cold Rolling and Annealing	94
War-time Economics	95
Preliminary Pesearches on the Action of Water on Copper Pipes	96
Import Licensing of Aluminium	96
The Manufacture of Pig Iron in America. By William A. Haven *The author describes the designs, equipment and practices which characterise modern American blast furnaces.*	97–101
Hypersilid—A High-silicon Acid-resisting Alloy	102
Low Lead-Silver Alloys for Bearings	103–104
Practical Aspects of Working Aluminium and Its Alloys	105
The Production of Aluminium and Aluminium-Alloy Sheet. By William Ashcroft *In this article the avthor deals with the main practical aspects of production and the great progress made during the last twenty years.*	106–110
Working Aluminium-Alloy Tubes and Sections. By Norman L. Brown	110
The Production and Treatment of Aluminium-Alloy Castings. By a Special Contributor	111–114
The Forging of Aluminium Alloys. By a Special Contributor *The principles of the forging of aluminium alloys are outlined, and comparison made with similar operations for steel. The metallurgical factors and various operations involved are discussed. The work is of a highly specialised nature.*	115–116
The Extrusion of Aluminium Alloys. By R. Worsdale *The process has assumed increasing importance as a result of developments in aircraft and certain road transport vehicle construction. A brief outline of the process employed is given.*	117–120
Working Aluminium and Aluminium-Alloy Sheet. By a Special Contributor	121–122
The Machining of Aluminium	122
The Polishing, Plating and Anodising of the Aluminium Light Alloys. By E. E. Halls *Practical methods of surface treatment are discussed.*	123–126
Japanese Research on Aluminium Production	126
The Hot Galvanising of Wire. By a Special Contributor	127–128
Refractory Materials for Reverberatory Furnaces. By Alfred B. Seale	129–131
Temperature Control and Superheating for Cast Iron	132
Copper - Zirconium - Cadmium Bronze	133–134
The Structure and Mechanical Properties of Special Cast Irons	134
Metal Prices	136

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Brazed Tubes	,,	0	1	3
Rods Drawn	,,	0	0	11
Wire	,,	0	0	10½
*Extruded Brass Bars	,,	0	0	7¼

COPPER.

Standard Cash		£44	5	0
Electrolytic		62	0	0
Best Selected		60	10	0
Tough		61	5	0
Sheets		96	10	0
Wire Bars		65	10	0
Ingot Bars		65	10	0
Solid Drawn Tubes	lb.	0	1	1½
Brazed Tubes	,,	0	1	1½

FERRO ALLOYS.

‡Tungsten Metal ° Powder, nominal	lb.	£0	4	5½
‡Ferro Tungsten ° nominal	,,	0	4	4
Ferro Molybdenum ° ,,	...		5	7
Ferro Chrome, 60-70% Chr. Basis 60% Chr. 2-ton lots or up.				
NOMINAL: 2–4% Carbon, scale 15/– per unit	ton	45	5	0
4–6% Carbon, scale 12/6 per unit	,,	39	10	0
6–8% Carbon, scale 12/6 per unit	,,	38	10	0
8–10% Carbon, scale 12/6 per unit	,,	38	10	0
§Ferro Chrome, Specially Refined, broken in small pieces for Crucible Steelwork. Quantities of 1 ton or over. Basis 60% Ch. Guar. max. 2% Carbon, scale 18/6 per unit	,,	58	0	0
Guar. max. 1% Carbon, scale 19/6 per unit	,,	60	0	0
§Guar. max. 0·5% Carbon, scale 20/– per unit	,,	71	0	0
‡Manganese Metal 97–98% Mn	lb.	1/5½ to 1/9		
‡Metallic Chromium	,,	3/5½ to 3/7½		
§Ferro-Vanadium 50–55%	,,	0	14	0
§Spiegel, 18–20%	ton	12	2	6
Ferro Silicon—				
Basis 10%, scale 3/– per unit nominal	ton	15	0	0
20/30% basis 25%, scale 3/6 per unit	,,	15	10	0
45/50% basis 45%, scale 5/– per unit	,,	19	0	0
70/80% basis 75%, scale 7/– per unit	,,	29	10	0
90/95% basis 90%, scale 10/– per unit	,,	40	0	0
§Silico Manganese 65/75% Mn, basis 65% Mn	,,	26	0	0
§Ferro-Carbon Titanium, 15/18% Ti	lb.	0	0	7½
Ferro Phosphorus, 20–25%	ton	35	0	0
§Ferro-Molybdenum, Molyte	lb.	0	5	3
§Calcium Molybdate	,,	0	5	0

FUELS.

Foundry Coke—			
S. Wales	£1	18	0
Scotland	1	15	0
Durham	1	17	0
Furnace Coke—			
Scotland	1	9	0
S. Wales	1	7	6
Durham	1	9	2

GUN METAL.

*Admiralty Gunmetal Ingots (88 : 10 : 2)		£94	0	0
*Commercial Ingots		80	0	0
*Gunmetal Bars, Tank brand, 1 in. dia. and upwards	lb.	0	1	1½
*Cored Bars	,,	0	1	3½

MANUFACTURED IRON.

Scotland—			
Crown Bars	£12	15	0
N.E. Coast—			
Rivets		—	
Best Bars	13	5	0
Crown Bars	12	18	0
Lancashire—			
Crown Bars	12	15	0
Hoops	13	11	0
Midlands—			
Crown Bars	12	15	0
Marked Bars	15	15	0
Unmarked Bars		—	
Nut and Bolt Bars	11	0	0
Gas Strip	13	12	0
S. Yorks.—			
Best Bars	12	5	0
Hoops	13	12	6

PHOSPHOR BRONZE.

*Bars, "Tank" brand, 1 in. dia. and upwards—Solid	lb.	£0	1	1½
*Cored Bars	,,	0	1	3½
†Strip	,,	0	1	1
†Sheet to 10 W.G.	,,	0	1	1½
†Wire	,,	0	1	3
†Rods	,,	0	1	3½
†Tubes	,,	0	1	9
†Castings	,,	0	1	3

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†15% Phos. Cop. £35 above B.S.
†Phos. Tin (5%) £30 above English Ingots.

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Hæmatite M/Nos.	£6	4	6
Foundry No. 1	5	12	0
,, No. 3	5	9	6
N.E. Coast—			
Hæmatite No. 1	6	4	6
Foundry No. 1	5	11	0
,, No. 3	5	8	0
,, No. 4		—	
Silicon Iron		—	
Forge		—	
Midlands—			
N. Staffs. Forge No. 4		—	
,, Foundry No. 3	5	10	0
Northants—			
Foundry No. 1	5	11	6
Forge No. 4		—	
Foundry No. 3	5	7	6
Derbyshire Forge	5	0	0
,, Foundry No. 1	5	13	0
,, Foundry No. 3	5	10	0
West Coast Hæmatite	6	4	6
East ,, ,,	6	4	6

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,, Wire	55	10	0
Brass	47	0	0
Gun Metal	72	0	0
Zinc	10	0	0
Aluminium Cuttings	72	0	0
Lead	11	10	0
Heavy Steel—			
S. Wales	3	0	3
Scotland	2	19	0
Cleveland	3	1	0
Cast Iron—			
Midlands	3	7	0
S. Wales	3	7	9
Cleveland	3	6	6
Steel Turnings—			
Cleveland	2	7	0
Midlands	2	0	3
Cast Iron Borings—			
Cleveland	2	0	0
Scotland	2	0	0

SPELTER.

G.O.B. Official	£25	15	0
Hard		—	
English	26	10	0
Empire	26	10	0
Re-melted	16	10	0

STEEL.

Ship, Bridge and Tank Plates—			
Scotland	£11	10	6
North-East Coast	11	10	6
Midlands	11	13	0
Boiler Plates (Land) Scotland	11	10	6
,, ,, (Marine) ,,		—	
,, ,, (Land) N.E. Coast	11	10	6
,, ,, (Marine) ,,		—	
Angles, Scotland	11	8	0
,, North-East Coast	11	8	0
,, Midlands	11	8	0
Joists	11	8	0
Heavy Rails	10	3	0
Fishplates	14	10	0
Light Rails	12	2	6
Sheffield—			
Siemens Acid Billets	11	17	6
Hard Basic	10	7	6
Medium Basic	10	5	0
Soft Basic	10	0	0
Hoops	13	11	0
Manchester—			
Hoops	13	11	0
Scotland, Sheets 24 B.G.	16	2	6

¶HIGH-SPEED TOOL STEEL.

Finished Bars 14% Tungsten	lb.	£0	3	0
Finished Bars 18% Tungsten	,,	0	3	10
Extras:				
Round and Squares, ½ in. to ¼ in.	,,	0	0	3
Under ¼ in. to ⅛ in.	,,	0	1	0
Round and Squares, 3 in.	,,	0	0	4
Flats under 1 in. × ⅜ in.	,,	0	0	3
,, ½ in. × ¼ in.	,,	0	1	0

TIN.

Standard cash	£246	10	0
English	246	15	0
Tin Plates I.C. 20 × 14 box	£1 11	0/£1 12	0

ZINC.

English Sheets	£30	12	6
Zinc Boiler Plates	28	12	6
Battery Plates		—	
Boiler Plates		—	

LEAD.

Soft Foreign	£25	0	0
Empire	25	0	0

* McKechnie Brothers, Ltd., Feb. 12. † C. Clifford & Sons, Ltd., Feb. 12. ‡ Murex Limited., Feb. 12.
Subject to Market fluctuations. Buyers are advised to send inquiries for current prices when about to place order.
§ Prices ex warehouse, Feb. 12. ¶ The prices fluctuate with the price of Tungsten.